PROMOTING SELF-REGULATED LEARNING PROCESSES THROUGH INTERACTIONS IN RESOURCE-BASED DIGITAL LEARNING ENVIRONMENTS

by

Lisa Ann Ferrara

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STATEMENT OF DISSERTATION APPROVAL

The dissertation of **Lisa Ann Ferrara**

has been approved by the following supervisory committee members:

Kirsten R. Butcher	, Chair	**April 21, 2017** Date Approved
Anne E. Cook	, Member	**April 21, 2017** Date Approved
Robert Zheng	, Member	**April 21, 2017** Date Approved
Eric Poitras	, Member	**April 21, 2017** Date Approved
Tamara Sumner	, Member	**April 21, 2017** Date Approved

and by **Anne E. Cook** , Chair/Dean of

the Department/College/School of **Educational Psychology**

and by David B. Kieda, Dean of The Graduate School.

ABSTRACT

Self-regulated learning with online resources is a prevalent experience for today's learners, but these online learning opportunities frequently yield disappointing results when considering students' learning outcomes. The current research examined the impact of different forms of navigational scaffolds to help learners self-regulate their learning behaviors as they attempted to form well-organized, conceptual knowledge from varied online resources. Experiment 1 examined scaffolds for two potentially useful learning paths: conceptual coherence (depicted in a graphical overview of the domain) and foundational knowledge (depicted via visual cues about the importance of a concept to the domain). Results revealed no effects of a conceptual coherence scaffold on participants' self-regulated learning behaviors or learning outcomes. When foundational knowledge scaffolds were present, participants used more effective self-regulated learning strategies on higher priority concepts, but learning did not improve. Participants utilized prescribed learning paths only 63% of the time and thus may not have benefitted from them. Experiment 2 investigated the impact of using a dynamic, automatic scaffold to structure learning paths through the online resources; both learning path (coherence vs. foundational) and amount of learner navigational control (low vs. high) were varied. Results revealed that when a foundational knowledge path was enforced, learners executed more effective self-regulated learning strategies and gained a deeper understanding of conceptual relationships. Overall findings suggest that learners working

with digital resources benefit from navigational guidance that helps them focus on foundational ideas in an online, self-regulated environment.

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CHAPTER 1

INTRODUCTION

Recent evidence suggests that students go online to access information more than any other information source (Graham & Metaxas, 2003; Walraven, Brand-Gruwel, & Boshuizen, 2009), regardless of whether the assignment requires an Internet-based component or not (Graham & Metaxas, 2003; Walraven et al., 2009). School administrators and teachers are increasingly integrating online learning into existing curricula, partly because modern students expect to use this type of technology as part of their formal education (Graham & Metaxas, 2003; Project Tomorrow Research Team, 2013) and partly because constructive interactions in technology-intensive learning environments have been shown to facilitate deeper learning of complex subjects (Rosen & Salomon, 2007). Despite widespread educational interest in using online systems and resources for learning, research evidence calls into question the effectiveness of learners' abilities to self-regulate their behaviors while learning from digital resources that are available online (Azevedo, Guthrie, & Seibert, 2004; Goldman, Braasch, Wiley, Graesser, & Brodowinska, 2012).

1.1 Challenges in Learning From Online Resources

Learners often struggle to make substantial knowledge gains when using digital resources available online, likely because they fail to manage and engage in effective processing when learning from these resources (Azevedo, Guthrie, & Seibert, 2004; Goldman et al., 2012). While learning from material available online, learners must manage their learning as they encounter multiple resources and highly varied media (e.g., text, diagrams, simulations). Moreover, learning from digital materials is an inherently nonlinear task; hyperlinks between materials can result in learners moving frequently between materials but becoming disoriented about their learning paths (Rouet, 2006; Turetken & Sharda, 2007). For these reasons, learning from online materials is a cognitively demanding task that can overwhelm the learner and result in little or no knowledge gain after studying (Azevedo & Cromley, 2004).

Because learning from digital resources typically is managed by the learner, researchers interested in understanding more about when learning from those resources is successful have frequently grounded their research in the study of self-regulated learning (Azevedo, Guthrie, & Seibert, 2004; Goldman et al., 2012).

1.2 Self-Regulated Learning

Self-regulated learning (SRL) refers to the process of guiding one's own learning through a combination of metacognition, strategic action, and personal motivation to learn (Pintrich, 2000; Zimmerman, 1990, 2002). Prior research of SRL activities has found that learners who engage in metacognitive processing and who make strategic decisions during their learning task typically experience greater learning gains and more positive academic outcomes (Bannert, 2006; Pintrich, 2004). During SRL in an online context, learners direct their own learning by selecting a unique learning path through a collection of available online resources. When learners are accessing and attempting to learn from multiple online resources, both the instructional context and the form of access to the materials matters. Learners enrolled in online classes, for example, typically are accessing digital resources via a lesson that has been developed by an instructor within a learning management system. Accordingly, digital resources in an online class lesson have been (at least to some extent) curated, organized, and provided within an instructional context that aligns the selected resources to learning objectives from the class. In an online class, the instructor's design and organization of materials within the learning management system creates a learning path for the student to follow. In contrast, SRL in online environments refers to the process by which a learner self-manages a learning path through digital resources. Instead of following a prescribed path through a specific set of resources, students engaged in SRL with online resources must choose which materials to study, for how long, and when to quit. In online SRL, learners who attain positive learning outcomes are reflective about their learning path and choose strategic actions that demonstrate their thoughtful attention about how to proceed through the online resources; this includes goal-directed navigation and evaluation of online resources (Goldman et al., 2012). In fact, Goldman et al. (2012) found that strategic decision-making (e.g., deciding what sites to read, when to continue/discontinue reading, and why to leave a website) was a key distinction in the self-regulated processes of good and poor learners engaged in online study such that good learners employed significantly more of these navigational decision-making strategies than poor learners. These data suggest that learning strategies (strategic actions) during SRL are deployed when a learner is engaged in metacognitive processing during the learning task. Indeed, additional research has also found that learners who strategically coordinated between multiple resources (going back and forth between materials) and iteratively reflected on task progress made more verbal statements that indicated their use of planning and monitoring metacognitive processes (Azevedo, Guthrie, & Seibert, 2004; Azevedo, Moos, Greene, Winters, & Cromley, 2007; Azevedo & Witherspoon, 2009). Therefore, one can conclude that although not directly observable, metacognitive processing found to be beneficial in SRL outcomes can inform or result from strategic actions and decisions that learners make during online learning tasks.

Research in SRL frequently makes use of the terms “SRL processes” (Greene & Azevedo, 2010; Moos, 2011) and “SRL strategies” (Azevedo, Guthrie, & Seibert, 2004; Salmerón, Kintsch, & Kintsch, 2010; Schunk, 2007). SRL strategies and cognitive processes are tightly linked in that the (internalized) cognitive processes lead to (externalized) strategies (Meijer, Veenman, & van Hout-Wolters, 2006; Zimmerman, 1990). For the purposes of clarity in this document, Meijer, Veenman, and van Hout-Wolters (2006) and Zimmerman’s (1990) distinctions between processes and strategies are adopted; strategies are defined as observable behaviors during SRL and processes are defined as internalized cognition leading to observable behaviors.

1.3 Self-Regulated Learning Processes

As the internalized processes in which a learner engages during a SRL episode, SRL processes guide decisive and strategic actions taken by a learner (Zimmerman, 1990). The most frequently discussed and studied SRL processes in the SRL literature are metacognitive processes (Butler & Winne, 1995; Pintrich, 2000; Schunk, 2007; Schunk & Zimmerman, 1997). Within SRL theories, metacognitive processes can generally be categorized into three phases: planning, monitoring, and reflection (Fogarty, 1994; Meijer et al., 2006). Planning processes are cognitive thoughts used to orient the learner within the learning episode or task. Planning processes include activating prior knowledge (Azevedo, Guthrie, & Seibert, 2004) and engaging in a task analysis of expected outcomes for setting learning goals (Zimmerman, 2002). Monitoring processes occur when the learner considers the relevancy of information encountered during the learning task to her own understanding of the subject (Azevedo & Cromley, 2004; Azevedo, Guthrie, & Seibert, 2004; Azevedo & Witherspoon, 2009; Bannert, 2006; Winne & Hadwin, 1998). Reflection processes occur when the learner evaluates the outcome of the learning task, which includes evaluation of the strategies that were used as well as her understanding (Schunk, 2007). While it may seem that planning, monitoring, and reflection should occur in a fixed order during a SRL task, SRL models depict these processes as iterative and recurring during a learning episode (Butler & Winne, 1995; Pintrich, 2004; Winne & Hadwin, 1998). Indeed, experimental analysis of online SRL tasks has shown that metacognitive processes do occur iteratively throughout a learning event (Azevedo & Witherspoon, 2009).

1.4 Self-Regulated Learning Strategies

SRL strategies are defined as the overt actions that learners deploy during an SRL episode to make progress on a learning task (Zimmerman, 1990). As previously mentioned, engagement in SRL processes during a learning task correlates with the use of certain SRL strategies during the learning task (Azevedo et al., 2007; Azevedo, Guthrie, & Seibert, 2004; Azevedo & Witherspoon, 2009; Bannert, 2006; Goldman et al., 2012).

SRL processes determine which SRL strategy a learner will execute. For example, by activating prior knowledge (a planning process), a learner can identify a learning path through hyperlinked online resources that addresses her knowledge gaps. As she learns from one resource and moves to another, she can monitor her emerging understanding of a domain (a monitoring process) to allow her to search for and retrieve online resources that contain information that is likely to resolve her current confusion (an information retrieval strategy). The degree to which a learner engages in planning, monitoring, and reflection processes determines the types of strategic actions that will be taken during the task (Azevedo & Cromley, 2004; Goldman et al., 2012; Winne & Hadwin, 1998). In the absence of think-aloud protocols, observing learners' SRL behaviors (their strategies) provides indirect evidence of the SRL processes in which they are engaged during an online learning episode.

SRL researchers have identified a number of common strategies that learners employ during online learning, including selecting new resources throughout an online learning task, adding new content to an essay during iterative revisions, rereading and revisiting resources, typing in keywords to search for learning resources, and copying information from resources (Azevedo, Guthrie, & Seibert, 2004). However, not all of the strategies used by learners result in positive learning outcomes.

1.4.1 Effective Versus Ineffective SRL Strategies

A number of SRL strategies have been found that predict successful learning outcomes in online SRL tasks. Azevedo, Guthrie, and Seibert (2004) found that learners who made significant knowledge gains during learning with materials online used targeted information seeking, that is, they sought out and selected information that addressed knowledge gaps in their prior knowledge of the topic. Goldman et al. (2012) found that learners with better learning outcomes used more goal-oriented navigation, including spending more time on websites evaluated as having more relevant content and frequently revisiting websites throughout the learning task. Azevedo, Guthrie, et al. (2004) and Azevedo, Moos, et al. (2007) found that better self-regulated learners coordinated information found in individual resources, synthesizing information across multiple resources, and revisited learning goals to reflect on their work products. The strategies just described – targeted information seeking, goal-oriented navigation, synthesizing information, and revisiting learning goals – were correlated with increased learning outcomes and, as such, are classified as effective learning strategies in this work. In contrast, strategies that learners use during an online learning task which are not correlated with successful learning outcomes are classified as ineffective learning strategies. Examples of ineffective strategies identified in online learning are less targeted searches for information (i.e., searches for general topic keywords instead of specific concepts relating to one's current understanding) and copying information from online resources directly into the work product (Azevdeo, Guthrie, & Seibert, 2004).

A key characteristic of effective SRL strategies is active cognitive processing of information from the online resources that involves cognitive processes that go beyond general encoding of information. For example, coordinating information between multiple resources (an effective SRL strategy) requires comparing and evaluating information from multiple resources to synthesize the information whereas copying and pasting information from an online resource (an ineffective SRL strategy) requires an overt action by the learner, but no cognitive manipulation of the information. Effective strategies typically involve the learner transforming the information being received from the online resource by higher order processing. For example, Azevedo, Guthrie, and Seibert (2004) found that learners who used effective SRL strategies more often drew inferences from online resources, elaborated on their own knowledge of the domain, and created hypotheses about the subject matter (heart and circulatory system). The effective SRL strategies exhibited by learners in Azevedo, Guthrie, and Seibert (2004) are associated with inferential cognitive processing. Inferential and integrative processing lead to deeper levels of understanding, as established in the comprehension literature and posited by a well-known model of comprehension: the Construction-Integration model (Kintsch, 1994; van Dijk & Kintsch, 1983).

1.5 Levels of Comprehension and SRL

The differentiation between effective and ineffective strategies aligns with levels of understanding proposed by comprehension theory. The Construction-Integration (CI) model distinguishes between three levels of knowledge representations: the surface level, the textbase level, and the situation model (Kintsch, 1994). A surface level representation is formed by encoding the specific details of a text (e.g., exact words and sentences), manifesting as rote memorization of a resource. A textbase representation encodes the semantic meaning of a text as propositions (Kintsch, 1994), which facilitates recall of basic ideas and declarative knowledge derived from learning materials (Mcnamara, Kintsch, Songer, & Kintsch, 1996). The surface and textbase levels of knowledge representation encode information faithfully from learning materials; unfortunately, these representations tend to fade from learners' long-term memory relatively quickly, within about 2 weeks (Kintsch, 1994, 1998). The most flexible and durable knowledge representation is the situation model, which is formed when the learner integrates the propositions representing the semantic meaning of newly encountered information with prior knowledge. This resulting situation model facilitates inference, application, and knowledge transfer (Butcher & Kintsch, 2012); as such, students who develop the situation model can be considered to understand materials rather than simply remember them. To transform information into knowledge during online learning, learners need to participate in effective learning strategies that promote integrating information from resources into their prior knowledge, much like the situation-level processes identified in the CI model. In other words, self-regulated learners need to utilize effective SRL strategies during online learning to reach a deeper understanding of the online resources.

1.6 Navigation Challenges During Self-Regulated Online Learning

Most learners struggle to initiate effective SRL strategies spontaneously during a learning task (Winne & Perry, 2000). This problem may be exacerbated by online learning environments that provide learners with access to vast amounts of materials that can be retrieved quickly and easily. When engaged in SRL in online contexts, learners often utilize ineffective SRL strategies such as relying on quick, short keyword information searches (Thompson, 2013) as opposed to iterative searches based on an emerging understanding. Ineffective strategies may help speed task completion because a minimal number of resources are sought and accessed to complete the learning task; but the use of ineffective strategies also means that learners are not engaged in meaningful SRL processes. As a result, learners are likely forgoing the integrative and knowledge building cognitive processing associated with effective strategies, like monitoring emerging understanding or synthesizing information between multiple resources, resulting in shallow levels of understanding after online study. Use of ineffective strategies may be an indication that learners are not able to monitor their emerging understanding successfully. Especially problematic in online SRL, a failure to evaluate ones' own understanding during SRL leaves a learner little direction on which resources to select next for optimal learning, resulting in nonoptimal learning paths through the domain resources (Quintana, Zhang, & Krajcik, 2005). Nonoptimal learning paths through nonlinear content, such as random or minimal access of online resources, are problematic because the order in which resources are found and accessed can affect comprehension (Britt, Rouet, & Perfetti, 1996; Salmerón, Kintsch, & Cañas, 2006). To promote use of effective SRL strategies during online study, learners may need explicit guidance in selecting and identifying appropriate resources and navigating an optimal learning path through those resources.

1.7 Using External Regulation to Improve Online Learning Outcomes

External regulation of learning paths has been used as an intervention to facilitate online SRL (Azevedo & Cromley, 2004; Azevedo, Cromley, & Seibert, 2004; Azevedo, Guthrie, & Seibert, 2004; Butcher & Sumner, 2011). External regulation is a general approach to instructional facilitation, intended to offload some of the requirements of monitoring and selecting meaningful learning paths from the learner to an external entity (i.e., a human facilitator or a programmed system).

1.7.1 Human Tutors as External Regulators in SRL

One type of successful intervention in supporting effective SRL strategies has been the use of human tutors who explicitly direct learners' behavior during a study task (Azevedo, Cromley, & Seibert, 2004). In Azevedo, Cromley, and Seibert (2004), human tutors sitting with an individual learner during an online task provided broad support for effective SRL strategies, including reminders to evaluate comprehension after reading a resource (essentially directing learners to monitor their emerging understanding), prompts to synthesize information across multiple resources (an effective SRL strategy for knowledge building processes), and direction on what the next optimal resource or information search goal would be (directing learners on strategic learning paths through the resources). As may be expected, participants in the externally regulated condition had better learning outcomes, showed more evidence of metacognitive processing like source monitoring, and used more effective SRL strategies such as iterating between multiple resources to synthesize the information. Participants who only were given a list of domain learning subgoals at the beginning of the learning task did not engage in these effective SRL strategies (Azevedo, Cromley, & Seibert, 2004). In a larger follow-up study, these results were corroborated when 128 junior high and high school students were assigned to either an externally regulated condition with a human tutor or a self-regulated condition with no tutor: participants in the externally regulated condition regulated learning with effective strategies more often, gained significantly more declarative knowledge, and could produce more advanced representations of the heart and circulatory system than participants in the SRL condition (Azevedo et al., 2007).

Studies using a human tutor for SRL support (Azevedo et al., 2007; Azevedo, Cromley, & Seibert, 2004) have been effective in prompting students to engage in critical SRL strategies likely because they provided adaptive feedback that responded to learners' individual processes and behaviors during an online learning task. Human tutors provided a complex form of adaptive feedback and personalized intervention as they guided learners through multiple resources along a meaningful path in a new domain. Indeed, in studies on human tutoring, tutors have been found to support deep learning of tutees by drawing explicit attention to gaps in understanding and providing conceptual guidance during a study session (Person, Graesser, Kreuz, & Pomeroy, 2003). Thus, using human tutors as a form of external regulation in SRL research (Azevedo et al., 2007; Azevedo, Cromley, & Seibert, 2004) essentially may turn the SRL learning task into a guided tutoring session that happens to use online content. This raises three important and concerning questions for research in SRL environments: 1) When does external regulation negate the self-directed nature of SRL? 2) What interventions are most critical in promoting improved strategies and processing during SRL? 3) Can effective interventions for SRL be implemented as large-scale, autonomous solutions? These three issues are discussed below.

When an SRL intervention provides robust, externally driven assistance in strategy selection during a learning task, it calls into question the boundaries between SRL and learning that is directed by others. Being able to recognize and deploy effective SRL strategies is something that learners must be able to do themselves either initially or after training. SRL theories argue that metacognitive monitoring of learning task completion and emerging understanding is a form of internally generated feedback that learners use to adapt their SRL strategies (Butler & Winne, 1995; Moos, 2011; Winne & Hadwin, 1998). When such feedback is provided by external means (i.e., human tutors) in constant and reliable ways, learners may not develop the cognitive skills and study habits necessary to engage in effective SRL processes on their own. One way to address this question is to determine the effectiveness of interventions that vary the degree of student choice allowed during a supported SRL task without fully removing the potential for self-directed variations in the learning path or process.

The second limitation of existing SRL studies using external regulation (Azevedo et al., 2007; Azevedo, Cromley, & Seibert, 2004) is that the interventions are too broad to understand which specific types of intervention are most critical in online learning environments. Human tutors in previous studies provided robust support and assistance in many ways. Support included prompting learners to engage in prior knowledge activation, reminding learners to monitor their emerging understanding, guiding the learners to select resources based on identified knowledge gaps, and encouraging learners to draw out or summarize what they learned from each resource. Accordingly, when the SRL task was externally regulated by human tutors, the tutors took responsibility for several key metacognitive processes that successful SRL learners should be able to deploy spontaneously. When robust and comprehensive SRL intervention is provided by human tutors, it is difficult to determine which SRL processes and strategies are most important in developing effective self-regulated learners who can work independently and successfully. Is it possible that prompting students to activate or engage in selected, key strategies is sufficient to promote effective SRL and better learning outcomes? For example, would deeper learning outcomes be observed if a human tutor only provided support in moving through online resources? This question is especially important when considering the feasibility of implementing SRL interventions and brings us to the third limitation: scalability.

Because most learning opportunities in the modern learning era are self-regulated tasks with online resources, a worthwhile practical goal of understanding SRL is to develop effective interventions that can support a wide variety of learners in highly varied contexts. Providing a human tutor to every self-regulated learner is not a scalable intervention as it violates inherent constraints on contexts (when and where learners can study) as well as clear limits on human resources. One-on-one human tutoring would require too many tutors to be implemented in contexts except small, focused (and well-funded) educational settings. Scalable interventions likely need to be implemented in ways that provide automatized support to learners via a digital interface. However, developing such automated support requires both an understanding of what processes are critical to SRL development as well as an evaluation of how key SRL processes could be supported in automated ways.

1.7.2 Programmed External Regulation in SRL

Examples of automated scaffolds for knowledge development can be seen in the field of intelligent tutoring. Intelligent tutoring systems (ITS) have demonstrated considerable success in using automatic, computer-generated forms of intervention to transition learners from novice to more expert knowledge in several domains, including physics and geometry (Graesser et al., 2004; Koedinger, Anderson, Hadley, & Mark, 1997). In ITS, models of expert knowledge (represented as a series of steps in a problem-solving process) serve as the basis for learning paths. Novices are guided through expert steps within a set of learning materials, starting first with basic concepts and then advancing to more complex skills or concepts as mastery is achieved in foundational areas. Throughout practice, computational models track learners' developing knowledge and adjust instruction and practice as needed. The computational knowledge modeling in an ITS allows decisions about the scope and sequence of instruction to be programmed into the system based on strict production rules that do not require frequent human intervention. As a result, an individual learner can use an ITS on her own (in absence of any supervision by a human tutor or teacher) and still experience a fully supported and customized learning experience. Thus, ITS are a highly scalable delivery method for customized instructional support of learners.

Despite being scalable at delivery, ITS are resource-intensive to develop. Some developers have estimated that it takes 200 hours of programming and development time to produce the equivalent of 1 hour of instruction (Morgan & Ritter, 2002). The domains in which ITS may be deployed also are somewhat more limited than those for which SRL support is needed. ITS have been most successful at providing feedback on problem-solving steps involved in the development of conceptual and procedural skills in well-structured domains (e.g., algebra and geometry). The nature of knowledge needed for problem solving in these well-structured domains is easier to define compared to the knowledge needed to make progress with the complex, ill-defined learning tasks that often form the basis of SRL with varied online resources.

1.7.3 A Case for Navigational Path Scaffolds During SRL

Research on instructional interventions provided by both human tutors and ITS demonstrate that guiding learners along well-chosen paths through domain content can be successful in promoting learning in complex science domains. Human tutors guide effective learning paths by directing learners to select resources based on the tutor's assessment of the learner's emerging understanding and knowledge gaps. ITS guide effective learning paths by presenting problems according to expert models of problem solving; in an ITS, an individual learning path is determined by analyzing the results of learner actions according to the expert model and sequencing problem-solving practice according to the skills/content that appear next in the model. Because SRL in online learning contexts requires moving between multiple resources that may vary in content and complexity, providing instructional supports that suggest an optimal learning path across online materials may be central in promoting effective SRL strategies, metacognitive processing and, ultimately, learning. It should be noted that creating navigational scaffolds to encourage optimal learning paths keeps inherent demands of SRL in place: although the connections between resources may become more explicit with additional scaffolds, learners are still in control of deciding which resources to learn from, when, and for how long.

1.8 Learning Paths and Online Resources

Effective self-regulated learners exercise strategic control over which resources they access and when each selected resource is accessed during the learning task. Learners' choices result in individualized learning paths along which they acquire information, develop subskills, and master concepts en route to domain mastery (Williams, 1996). The path a self-regulated learner takes through online resources is important because learning paths created by different approaches to understanding can impact knowledge development and learning outcomes (Reigeluth, n.d.; Salmerón et al., 2006). Research has found that learners who move through online resources along a learning path driven by conceptual coherence learn more than students whose paths are driven by interest (Salmerón et al., 2006). That is, learners who selected the next link in a progression according to domain coherence rather than their interest in reading the link experienced greatest gains during online study (Salmerón et al., 2006). This has important implications for SRL, since students may use a variety of strategies to determine their navigational paths through online content.

The Salmerón et al. (2006) finding that coherent learning paths across online materials lead to increased conceptual understanding is consistent with what would be predicted by the CI model (Kintsch, 1994; van Dijk & Kintsch, 1983). When concepts are learned in an order that prioritizes coherence across multiple resources, the concepts likely are easier to integrate. As a result, students should develop a situation model that can lead to knowledge transfer and application.

The importance of optimal learning paths in SRL also is suggested by research-based recommendations for teaching complex science topics. However, these recommendations differ from a coherence-based learning path. These recommendations discuss the importance of implementing learning paths that guide learners through critical domain concepts in order to promote a foundational knowledge model (Duncan & Rivet, 2013; Reigeluth, n.d.; Wiggins & McTighe, 1998). Foundational knowledge models are a base of understanding through which subsequent learning can more easily occur, essentially an integration network for assimilating new information. As VanLehn (2006) describes, in a macrolevel process of learning, there are some skills or knowledge that are more central and important to the domain, which must be learned first in order to gain a deep understanding of the domain. Concepts identified as central to the domain are important to master in order to understand subsequent domain details or examples, essentially, a foundation for understanding. The domain concepts that make up a foundational knowledge model are more central to the domain, also referred to frequently as ‘big ideas’ within a domain. Having a foundational understanding is important in learning because a foundational mental model is theorized as being necessary in cognitive psychology for which to integrate new knowledge onto and refine understanding in subsequent learning (Mayer, 1979). Because a foundational knowledge model focuses on developing a framework for subsequent knowledge, one can assume that new knowledge should be more easily attached to an existing foundational knowledge model and, as a consequence, a broader but potentially shallow understanding of the domain may be created. Specifically, it has been argued that focusing too heavily on central domain concepts in isolation from the rest of the domain can restrict deeper learning; focusing too much on big idea concepts outside of domain relationships reinforces the equivalent of textbase understanding and can lead to shallow learning, especially among novice learners (Spiro, Coulson, Feltovich, & Anderson, 1988; Spiro, Feltovich, Jacobson, & Coulson, 1992).

In online SRL, support is needed to guide learners along optimal paths because learners, especially low-knowledge learners, frequently lack the domain knowledge necessary to select coherent or meaningful link orders spontaneously (Butcher & Sumner, 2011; Macdonald & Mason, 1998; Salmerón et al., 2010). Indeed, Salmerón et al. (2010) studied the spontaneous learning paths of lower knowledge learners using web resources and found that these learners typically chose the order of resources based on personal interest or the position of a resource link on the screen rather than on the link's semantic relationship to a resource they had just read (Salmerón et al., 2010). While interest is theorized to motivate student engagement in SRL episodes (Keller, 2008; Pintrich, 2004; Pintrich & De Groot, 1990), it appears to be a poor basis for learning path selection. Learners may need support in order to more effectively move through the available resources in a SRL environment. By providing support for one SRL demand (i.e., evaluating relatedness of the next resource), cognitive resources are freed up for the multiple other cognitive demands of SRL with online resources, such as monitoring emerging understanding and engaging in deeper processing of varied multimedia content across the resources. However, this does raise the question of how optimal learning paths should be defined and identified within SRL systems.

1.8.1 Constructing Learning Paths for Online Learning

Identifying a learning path for a knowledge domain requires outlining the conceptual foundations and relationships among conceptual ideas; these foundations and relationships can be derived from published materials that depict learning progressions in a domain. Learning progressions are road maps of how concepts and subskills build upon one another to result in a larger domain of content knowledge (Duncan & Hmelo-Silver, 2009; Popham, 2007). Learning progressions are often represented visually as semantic-spatial displays, where major concepts in the domain are grouped together and relational connections are drawn as lines between concepts (AAAS Project 2061, 2007).

In science education, learning progressions are used to align curriculum, instruction, and assessment to a pathway of cognitive development for a specific content domain over time (Duncan & Hmelo-Silver, 2009; Duncan & Rivet, 2013; Schwarz, 2009). Project 2061, funded by the American Association for the Advancement of Science (AAAS), produced a series of conceptual strand maps that depict educational science benchmarks building over time to create scientific literacy. In the weather and climate strand map, for example, "The sun warms the air, land, and water" is a benchmark idea in the young elementary grades (kindergarten through second grade) within the "Temperature and Winds" strand (see Figure 1). The placement of the "The sun warms the air, land, and water" at the youngest grade levels indicates that this understanding of energy conservation is foundational to understanding the complexities of temperature and winds. The map explicitly indicates that the concept of conservation of energy should be learned before a learner can completely understand the underlying reasoning for heat transfer; the explicit relationship is indicated with a relational link that connects "The sun warms the air, land, and water" to more abstract and complex benchmarks: "A warmer object can warm a cooler one by contact or at a distance" (within the Temperature and Winds strand) and "When liquid water disappears, it turns into a gas (vapor) in the air and can reappear as a liquid when cooled…" (within the Water Cycle strand). Thus, the weather and climate strand map depicts a learning progression wherein the coherent understanding of the domain strand temperature and winds involves combining understanding of energy conservation, thermal dynamics, and temperature gradients over time (AAAS Project 2061, 2007).

Due to the interconnected relationships between ideas in a domain, there are usually multiple learning paths possible for a given instructional concept within a learning progression. The learning paths can be considered as potential pathways to acquiring the knowledge foundation for coherent understanding of the domain. Learning paths typically are employed by instructors and curriculum developers as tools for aligning instruction, but they could be productively exploited in an SRL environment as a tool for moving through learning materials. Much like a tutor or an ITS would direct the next most relevant concept for learning, a learning path could potentially guide a self-regulated learner to identify the next most relevant concept based on her current understanding and (subsequently) direct the learner to resources helpful for learning that concept. Learning progressions could guide learners along optimal learning paths by providing an explicit representation of how concepts are connected, revealing plausible learning paths within the domain. If low-knowledge learners navigate online resources using ineffective SRL strategies due to a lack of conceptual domain understanding (Salmerón et al., 2010), then it will be easier to monitor knowledge and understanding if there are clear conceptual relationships between the materials. Therefore, it would be logical to hypothesize that using a graphical organizer to display a meaningful learning progression through a domain could be a scalable and effective intervention for promoting SRL.

1.8.2 Using Graphical Organizers to Guide Learning Paths

One type of semantic-spatial display that has been used to communicate conceptual relationships within a domain is a graphical organizer. Graphical organizers, also referred to as concept maps (Novak & Gowin, 1984) or knowledge maps (O'Donnell, Dansereau, & Hall, 2002), are semantic-spatial representations of nodes and links where concepts are depicted in nodes and links between the nodes indicate relationships between the concepts. Graphical organizers, when studied prior to learning from text, can serve as advanced organizer aids for novices with low prior knowledge in a domain, resulting in improved factual recall of text main ideas (Nesbit & Adesope, 2006; O'Donnell et al., 2002) and text comprehension (Salmerón, Baccino, Cañas, Madrid, & Fajardo, 2009). It has been theorized that graphical organizers provide novices with a foundational knowledge structure into which new information can be assimilated and integrated during a learning task (Mayer, 1979).

Using a graphical organizer to present a domain overview may make learning paths salient for a learner, such that visual connections between the concepts (i.e., the relational links of a graphical organizer) make explicit the connections between concepts. Following a path established by such connections may serve as a scaffold for learners to integrate multiple resources according to their conceptual relationships. Because learning progressions provide multiple learning paths, learners would need to monitor their emerging understanding and strategically choose which concept to focus on when relational connections extending from one node diverge to more than one concept. This may be challenging because conceptual nodes in a graphical organizer usually are not visually annotated for items deemed critical to knowledge development, such as the importance of a concept within the domain. Learners can select a learning path that inadvertently misses a foundational concept within the domain or may select a haphazard path that jumps around the domain rather than progressing via relationships. In online

SRL tasks, learners who are not employing metacognitive monitoring processes may rely on ineffective strategies such as interest or screen position to decide on a learning path through available digital resources.

For example, in a typically drawn graphical organizer presenting an overview of weather and climate, both concepts “colder water sinks at poles” and “most weather phenomena are driven by convection currents” would be presented in a similarly styled node (see Figure 2). There is no additional information (visual or textual) indicating which concept is more central to the domain and should be studied first to gain foundational knowledge of weather and climate. The first concept (cold water sinks at poles) is an application of convection currents. To understand why cold water sinks at Earth’s poles a learner should have a foundational understanding of convection currents, which would provide important prior knowledge for integration of the information about cold water sinking at poles. Therefore, the second concept (convection currents) is more foundational to the weather and climate domain and critical for understanding very complex weather phenomena, including water currents at Earth’s poles. If learners need to acquire foundational knowledge before integrating examples, details, or knowledge of specific phenomena (as Duncan and Rivet (2013) and Wiggins and McTighe (1998) argue), then they likely will need scaffolds that help them to distinguish more important concepts from less important concepts in the domain and encourage them to select and attend to these important ideas first.

Despite the fact that graphical organizers depict concrete relationships, low-knowledge learners may struggle to interpret and use graphical organizers if they lack prior knowledge structures that help them focus on relevant areas of the visualization

(Amadieu, van Gog, Paas, Tricot, & Mariné, 2009; Nesbit & Adesope, 2006). Research on learning electrochemistry compared the use of a graphical organizer of chemical concepts and reactions to chemical reaction illustrations consisting of ionic redox reactions and charge transports (Brandt et al., 2001). Results revealed positive learning effects for participants who studied with the chemical reaction illustrations but no effects for the participants studying with the graphical organizers; Brandt et al. (2001) concluded that the graphical organizers were too novel and complex for their learners, thus complicating learning instead of facilitating knowledge acquisition. Other experiments using dynamic visualizations that were intended to make complex relationships more explicit for learners have found similar results; when learners do not have enough domain knowledge to orient themselves within the visual representation, learners do not process or integrate information from the representation, resulting in null or negative learning outcomes (Ploetzner, Lippitsch, Galmbacher, & Heuer, 2006). However, in ill-structured domains, the nature of relationship is complex. When the relationships between concepts are not direct or causal, oversimplifying the depiction of conceptual relationships could lead to misconceptions in domain understanding (Spiro & Jehng, 1990). Simplifying a domain representation has inherent problems, but another method of dealing with complexity is via the use of scaffolds or cues that guide learner processing. Research has found that visual cues may help learners understand a graphic organizer and the information that it depicts (Adesope & Nesbit, 2013; de Jong & van der Hulst, 2002).

1.8.3 Visual Cueing in Graphical Organizers

Visual cues can be defined as perceptually salient elements that are used to signal or highlight a specific area or element of a scene. Research on visual cues has revealed mixed results: some studies have shown that visual cues can direct learners to improve memory for and understanding of cued components (de Koning, Tabbers, Rikers, & Paas, 2007, 2009; Walraven et al., 2009) while other studies have not found positive outcomes associated with cueing (de Koning et al., 2009; de Koning, Tabbers, Rikers, & Paas, 2010; Kriz & Hegarty, 2007). When positive results have been found, studies mainly have been successful in increasing perceptual attention to the most relevant areas of focus during a learning task. de Koning et al. (2009) found that using a visual cue to direct students' attentional focus strategically (by decreasing luminance on subsystems not targeted by the current instruction, creating a spotlight effect) in an instructional animation had positive effects on learning, for both learners who received audio narration accompanying the animation and those who received no narration. Mautone and Mayer (2007) used visual signaling on graphs, annotating and highlighting critical features of the visuals prior to formal instruction on geological principles. Learners who studied the highlighted, annotated graphs prior to instruction scored higher on assessments measuring geological knowledge organization and integration, indicating deeper understanding (Mautone & Mayer, 2007). Research using audio narration during learning with a graphical organizer providing a sequencing scaffold through the visual found that the audio served as a scaffold for processing the graphical organizer, resulting in improved recall and transfer outcomes (Adesope & Nesbit, 2013). Despite the research demonstrating successful learning outcomes for cued items in complex visuals, it is important to note that a visual cue is an additional stimulus for the learner to process during a learning task. When too many stimuli are presented, there is a risk that learners may miss the perceptual cue (Varakin, Levin, & Fidler, 2004), become distracted from deeper learning processes because their attention is split between too many perceptual targets (Harp & Mayer, 1998; S. Lehman, Schraw, McCrudden, & Hartley, 2007), or experience processing difficulty (Sweller, 1988). Research using visual cueing in animated diagrams found that the cue drew visual attention but did not encourage active interpretation or processing of the underlying conceptual component, leading to null or weak learning outcomes (de Koning et al., 2010; Kriz & Hegarty, 2007). Therefore, visual cueing is not a guaranteed solution for promoting the positive learning outcomes with graphical organizers.

1.8.4 The Current Research

This work investigated how interventions from text comprehension and multimedia learning research can influence learners' SRL strategies during learning with online resources. It has already been established that effective SRL strategies promote deeper learning, that students rarely engage in effective SRL strategies spontaneously, and that tutored prompting can improve students' use of effective SRL strategies during study. However, little is known about when and how automatically provided interventions in an online SRL environment can prompt students to deploy those strategies when learning with online resources; moreover, it is not known if prompting the use of SRL strategies in the absence of human support will lead to increased learning. Overall, this work seeks to answer three questions:

- How are learning paths in an SRL environment using online resources influenced by scaffolds that can be automatically generated and provided to learners?
- How are the SRL strategies deployed by learners influenced by digital scaffolds that target learning path selection during learning with online resources?
- How are students' learning outcomes affected by digital scaffolds targeting learning path selection?

Experiment 1 examined two scaffolds that targeted different potentially useful learning paths: conceptual coherence (depicted in a graphical overview of the domain) and domain importance (depicted via visual cues about the importance of a concept to the domain). Experiment 2 examined the impact of using a dynamic, automatic scaffold to structure learning paths through domain content, varying both the type of learning path (coherence vs. importance) and the amount of control (low vs. high) afforded to learners in the system.

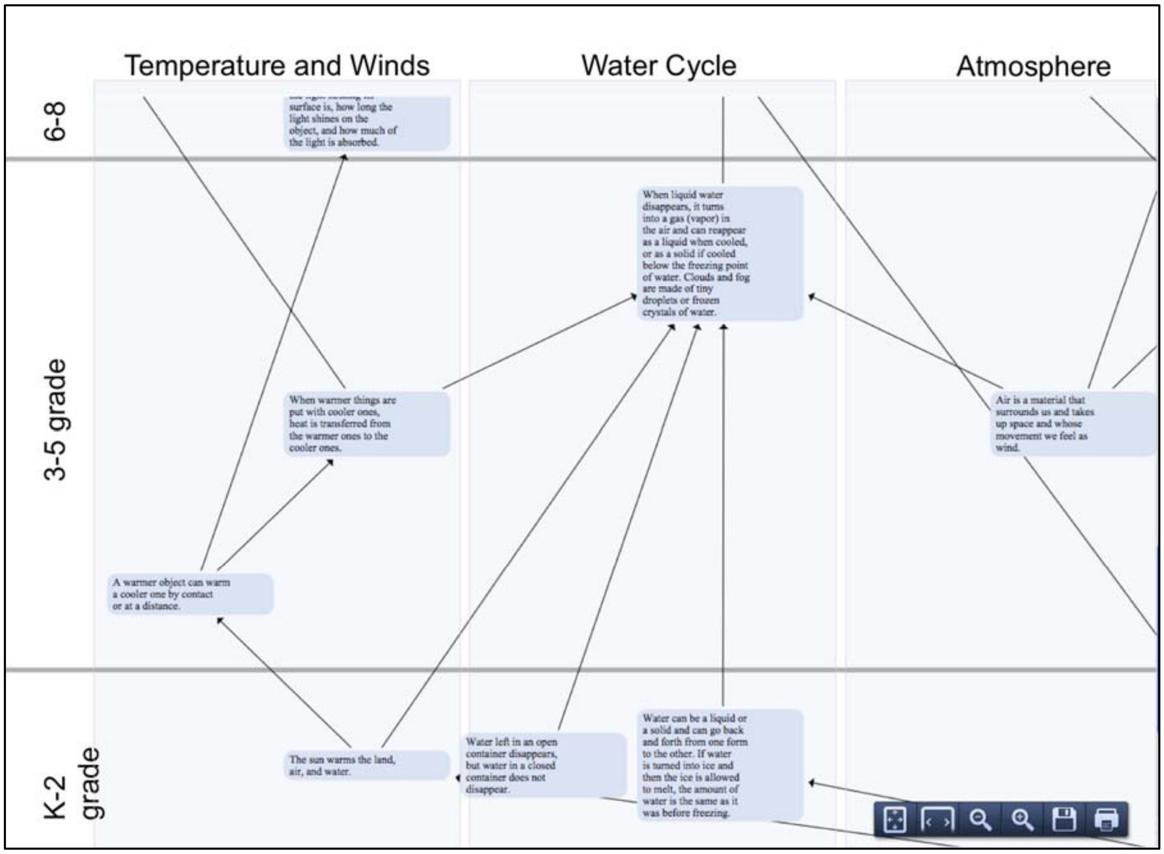

Figure 1. Excerpt of AAAS Weather and Climate strand map depicting weather and climate nodes and concept relationships as links.

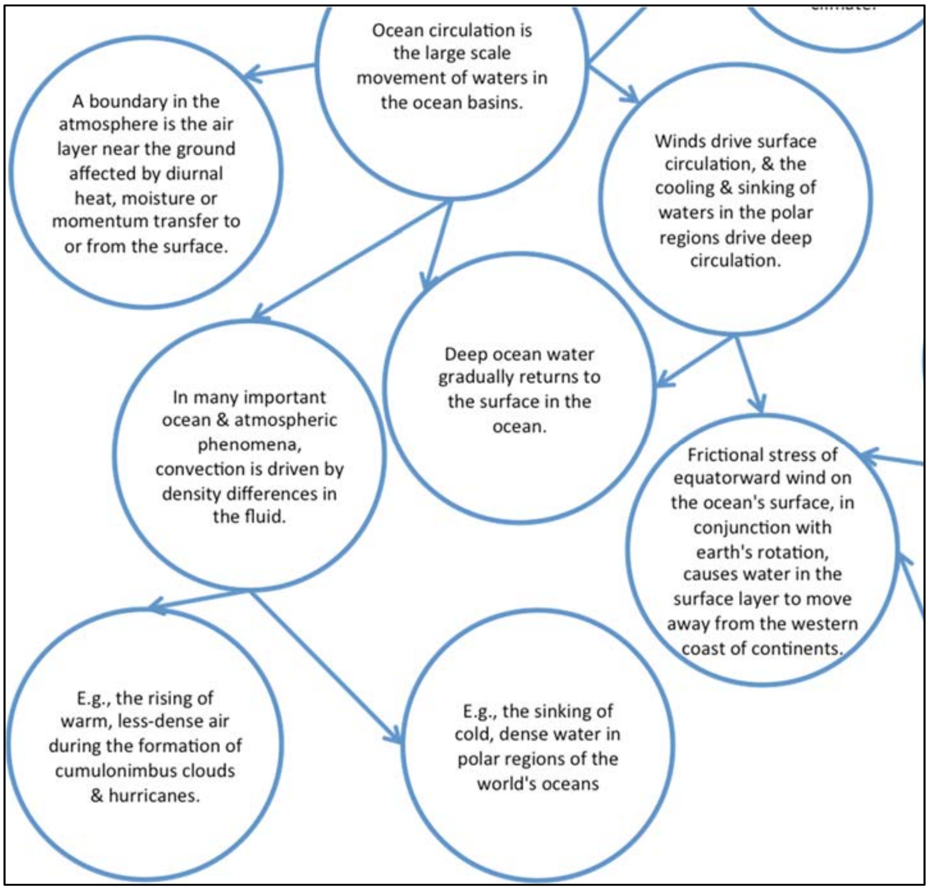

Figure 2. Excerpt of a graphical organizer for the weather and climate domain.

CHAPTER 2

EXPERIMENT 1

Experiment 1 was designed to investigate how effectively learners could utilize learning path guidance provided by a (static) graphical display and the extent to which such learning path guidance promoted deep learning of domain content. Experiment 1 used weather and climate science as the domain of study because it is complex and ill-structured; multiple processes and phenomena affect climate patterns and weather systems, making it difficult for novice learners to infer coherent, conceptual relationships between the information presented in multiple online resources. Experiment 1 investigated two independent variables to inform the research questions: a scaffold that depicted conceptual coherence and a scaffold that depicted foundational knowledge structures within the weather and climate domain.

The conceptual coherence scaffold was a graphical organizer that depicted the conceptual connections across key concepts within the weather and climate domain (see Figure 3a). The graphical organizer condition was compared to a control condition that utilized a text list of the same key concepts. Although the textual content of each condition was identical, the text list lacked explicitly depicted (visual) relationships between the concepts (see Figure 3b).

The scaffold for foundational knowledge sought to cue the importance of specific concepts to the overall domain within the graphical organizer or the text list. For this study, importance was defined as the extent to which a concept is critical for foundational understanding in the domain, determined by a subject matter expert who prioritized the top 18 recurring concepts in weather and climate online resources. In the graphical organizer, importance was indicated by visual cues in the form of node size. The most important concepts were placed in large nodes, moderately important concepts were placed in medium-sized nodes, and the least important concepts were placed in small nodes (see Figure 4a.). In the text list, importance was indicated by the order of the listed concepts starting with the most important concepts at the top of the list (Figure 4b). These cued conditions were compared to the uncued condition described above (see Figures 3a and 3b).

Introducing scaffolds for coherence and importance still left several SRL processes and behaviors in control of the learners. Specifically, learners still had the freedom to choose which resources to view and in what order, how long each resource should be studied, and how to integrate the knowledge gained from each resource into the learning task product.

2.1 Research Questions and Hypotheses

1. To what extent does a conceptual coherence scaffold affect learning path selection, SRL strategies, and knowledge outcomes while learning with online resources?

Hypothesis 1. Because presenting domain concepts in a graphical organizer should provide learners with information on how domain concepts relate to one another, the graphic organizer should help them synthesize resources into a coherent domain understanding. Thus, it was expected that learners who received a graphical organizer would navigate concepts by relationships, selecting the next nearest concept connected by a relational link during online study.

2. To what extent does a foundational knowledge scaffold affect learning path selection, SRL strategies, and knowledge outcomes while learning with online resources?

Hypothesis 2. Learners will make use of visual cues for domain centrality, navigating to highest priority concepts before lower priority concepts, spending more time on higher priority concepts compared to lower priority concepts, and demonstrating improved understanding of domain concepts.

3. To what extent does a conceptual coherence scaffold interact with a foundational knowledge scaffold to affect learning path selection, SRL strategies, and knowledge outcomes while learning with online resources?

Hypothesis 3. If hypothesis 1 is true, then moving through the online resources in a semantically related manner would promote a well-integrated and organized understanding of weather and climate, resulting in learners deeply understanding the weather and climate domain. If hypothesis 2 is true, then selecting the next important concept to address when a choice of two linked nodes are presented will improve foundational understanding. Thus, it was predicted that learners who received both scaffolds would produce positive learning outcomes on measures of deeper learning.

2.2 Methods

2.2.1 Design

Experiment 1 utilized a 2x2 factorial design. The independent variables were (1) a conceptual coherence scaffold (text list vs. graphical organizer) and (2) a foundational knowledge scaffold (no cues vs. domain centrality cues). Table 1 describes the four experimental conditions.

2.2.3 Participants

Participants were recruited via the University of Utah's College of Education research participation pool, which provides partial course credit for undergraduate and some graduate-level students in educational psychology courses. Seventy-five participants were recruited for the experiment. One participant terminated the study during the first session and one did not return to the second session. This resulted in a sample of 73 participants (60 females, 13 males). Table 1 lists the number of participants per condition.

2.2.4 Materials

2.2.4.1 Learning Assessments

Two assessments were developed with the assistance of a subject matter expert in atmospheric science. The assessments were designed to capture two levels of understanding: shallow and deep. These levels roughly correspond to the textbase and situation model levels (respectively) of Kintsch's (1994) CI model of comprehension. Textbase (shallow) levels of understanding were assessed by true/false questions that targeted factual knowledge about the domain. Situation model/deep understanding was assessed by short answer questions that required students to apply learned knowledge to novel situations.

2.2.4.1.1 True/False Questions

Twenty-five questions were developed to address facts about weather and climate science. Each question was worth one point, for a total of 25 points possible. The order of questions were randomized for each test time. This assessment had a time limit of 5 minutes during the experiment. Questions targeted important factual ideas within the domain; for example:

- Energy from the sun increases the temperature of the land, but it does not increase the temperature of the water. *(Correct answer: False)*
- The jet stream is the name for a fast moving stream of air in the upper atmosphere. *(Correct answer: True)*

2.2.4.1.2 Short Answer Application Questions

Four short answer questions were designed to measure a deeper understanding by asking the participant to apply their knowledge of weather and climate science to diagnose and explain an erroneous concept. For example: *The map below shows the pattern of surface ocean currents across the globe. Knowing that the wind influences surface ocean currents, would a map of wind currents across the globe look the same as the map below? Why or why not? Please explain the reasons for your answer and discuss at least one specific example from the map below.* This assessment had a 15-minute time limit during the experiment. Answers to application questions received two scores, as described below.

- Idea Unit Scores: The critical idea units necessary to adequately answer the question were identified by our subject matter expert (see Appendix B). For the short answer application question listed above, example idea units included (1) global winds form separate bands in each hemisphere and (2) general wind patterns are similar to ocean currents. Participants received one point for each idea unit present in the answer. Point values for individual items ranged from 3 to 6; a maximum score of 19 points was possible across all four questions.
- Quality of Explanation Scores: Answers also were scored for the depth of their explanation. A rubric was developed that was partially based on the conceptual change framework (Chi, 2008), the CI model of text comprehension (Kintsch, 1994), and ideal self-explanation statements (Renkl, 1997). Each explanation was scored on a scale of 0 to 5, where lower scores indicated answers that demonstrated the least depth and lowest understanding. For example, a score of 0 was assigned to answers that did not address the prompt at all or repeated the question; a score of 3 was assigned to answers that used keywords or simple descriptions to indicate an answer without explanation of how the concepts were applied/connected. The highest score, 5, was awarded to answers that connected one or more relevant terms to a correct explanation of the term(s), explained how terms were related, or provided a conceptual explanation that addressed the question (see Appendix B for a complete rubric). For the sample question provided earlier, a higher quality conceptual explanation would include a

principle-based explanation of both wind and ocean currents; a lower quality explanation would focus on nonessential details, like the Coriolis Effect on wind patterns. The maximum quality of explanation score was 20 points (5 points each on four questions). A Cohen's κ was calculated on a 20% data sample with two raters applying the rubric to participant responses to determine the reliability of the rubric. There was good agreement (κ = .78) between the two raters.

2.2.4.2 Learning Materials

Ten digital resources were provided to participants to learn about weather and climate to ensure that study participants had adequate background knowledge to compose an answer to the essay question. The online resources were hand-picked by the subject matter expert to ensure that the digital resources contained materials relevant to the essay prompt. The resources were available simultaneously in different browser tabs within a single browser window; this format allowed participants to move freely through and between individual resources during study. Resources included varied multimedia content, including videos, text, and diagrams.

2.2.4.3 Essay Prompt

An essay prompt was provided to guide students in generating a textual essay that demonstrated their knowledge of the domain topic. The essay prompt for participants was: "*Describe the role temperature gradients play in producing wind and ocean currents. In addition to temperature gradients, identify and explain other factors that influence the global pattern of atmospheric and ocean circulation.*" This prompt appeared at the top of a blank Microsoft Word document and was visible to participants throughout their writing task.

2.2.4.4 CLICK System

Participants' essays were parsed and analyzed by a web service known as CLICK that extracted the learners' understanding from the essay text, using a combination of natural language processing and graph theoretic techniques (Butcher & la Chica, 2010; Butcher & Sumner, 2011). The extracted understanding was compared to an expert model of understanding. The expert model was extracted (in the same manner as the novice models) from content contained in open educational resources found on the National Science Digital Library (http://nsdl.org). CLICK then tried to align the learner understanding onto the expert model, identifying differences between the two knowledge representations as misconceptions, fragmented knowledge, or missing concepts. The system returned a summary of potential problems (the misconceptions, fragmented knowledge, and missing concepts) to be provided to participants and translated into condition-based feedback by the essay revision interface.

2.2.4.5 Essay Revision Interface

The essay revision interface displayed the participant's original essay on the left side of one monitor and the condition-based feedback on the right side of the same monitor (see Figure 5). The essay portion of the screen allowed the participant to make edits to the essay content, including adding and deleting text. In text list conditions, only concepts identified by CLICK as potentially problematic in the participant's essay were listed on the right side of the screen. In graphical organizer conditions, potentially problematic concepts were highlighted in the visual display to distinguish them from the rest of the domain topics. The personalized scaffold meant that the number of highlighted problems (and therefore, number of resources that could be accessed) differed from participant to participant. CLICK returned a maximum of 10 sentences to the feedback interface, thus the number of concepts presented to the participants ranged from 1-10, with some concepts having more than one sentences tied to them. Clicking on a concept identified by CLICK revealed three pieces of additional scaffolding in the essay revision interface: 1) a list of 3-5 hyperlinks to recommended online resources, 2) a list of sentences in the essay from which the potentially problematic concept was derived by CLICK, and 3) a metacognitive prompt for learning task guidance (see Figure 6).

Recommended online resources during essay revision were a variety of websites accessible via the National Science Digital Library that provided a range of multimedia content including text, images, video, etc. CLICK scanned the metadata digital resources and only recommended them when the content was deemed semantically related to the domain concept targeted by the system. All CLICK-located recommended resources were reviewed by a subject matter expert who evaluated them for relevancy to the weather and climate domain, thus all resources were conceptually relevant for the concept they appeared. Clicking on a recommended resource hyperlink opened the digital resource in a new browser window on a second monitor.

Sentence highlights only appeared when a sentence within the essay that was relevant to a specific concept (as determined by CLICK) was selected by the participant and disappeared when a sentence relevant to a different concept was selected. If any text was modified in a highlighted sentence, the highlight would permanently disappear from the essay revision interface (acknowledging that a revision had been made). Sentence highlights were used in this study to assist participants in localizing feedback within their essay because prior research has found that learners articulated preferences and specific visual tools to identify problematic areas of an essay during writing feedback (Ferrara & Butcher, 2012; Nelson & Schunn, 2009).

Metacognitive prompts were used to encourage more thoughtful and focused revisions that addressed domain concepts from the conditional feedback. Prior research has found that learners presented with metacognitive question prompts can promote better learning outcomes (Chi, Siler, Jeong, & Yamauchi, 2001) and consistent with previous implementations of the CLICK system (Butcher & la Chica, 2010), metacognitive prompts (drawn from Chi et al., 2001) were used to encourage participant reflection in the system. For example, *Any thoughts on that?* and *Could you connect what you wrote with what you have read before?*

2.2.4.6 SRL Behaviors Rubric

For sentences on which conceptual feedback had been provided in the essay revision interface, participants' revisions were coded as effective or ineffective strategies, or as skipped if no observable action was taken. Consistent with comprehension theory (Kintsch, 1994) and research on successful SRL outcomes (Azevedo, Guthrie, & Seibert, 2004; Bannert, 2006; Pintrich, 2000), behaviors that replicated or repeated information from an online resource (i.e., failed to indicate manipulation or transformation of information from the online resources) were categorized as ineffective strategies (see

Table 2) while behaviors associated with the generation or transformation of new information were categorized as effective strategies (see Table 3). The number of sentence revisions made for the high importance concepts and for the low importance concepts were converted into percentages (number of times a type of behavior occurred divided by total number of observed revision behaviors for every domain concept). Cohen's κ was calculated on a 20% data sample with two raters applying the rubric to participant behaviors to determine the reliability of the rubric. There was good agreement ($\kappa = .74$) between the two raters.

2.2.4.7 Learning Path Rubric

Because learners could freely select any of the concepts presented in the essay revision interface at any point during the essay revision task, the order of concept selection served as evidence of a participant's self-selected learning path within the weather and climate domain. Movements between the interface concepts were observed and counted as either utilizing the conditional scaffold or not as described in Table 3. A Cohen's κ was run on a 20% data sample with two raters applying the rubric to participant movements to determine the reliability of the rubric. There was very good agreement ($\kappa = .84$) between the two raters.

Because the foundational knowledge scaffold was designed to guide learners to the more important concepts first, movements following foundational knowledge cues were counted when participants 1) began with the most important concepts (large size nodes), 2) moved to nodes within a level (e.g., the large nodes) before moving to lower levels. For example, if a participant moved from one large node to another, it was counted as a move along the foundational knowledge learning path. Similarly, if a participant moved to a medium sized node after having worked with all large size nodes, it was counted as a move along the foundational knowledge learning path. However, if a participant first selected a small node, it was not counted as a move along the foundational knowledge learning path. Similarly, if a participant had important concepts (large nodes) left to address but chose to move to a low priority concept (a small node), the move did not count as use of the foundational knowledge learning path.

Because the conceptual coherence scaffold was designed to help participants see the semantic relationships between concepts, movements in which the participant selected the most closely linked concept were counted as conceptually coherent. If a participant selected the next closest linked concept to address next, it counted as a move utilizing the conceptual coherence scaffold. If a participant chose to move between nodes that were not directly connected without clicking on any of the interconnected concepts, then the move did not count as use of the conceptual coherence scaffold.

At some places on the map, there was more than one correct move and, in the condition in which both scaffolds were provided, a move could count as use of both scaffolds. For each participant, the number of conceptually coherent moves were divided by the total number of moves, resulting in a percentage of moves made in a conceptually-coherent manner. Likewise, for each participant, the number of movements made in the order of conceptual importance were divided by the total number of moves to get a percentage of movements using the foundational knowledge learning path.

2.2.5 Equipment

All experimental sessions were conducted in a lab at the University of Utah. Experimental stations were equipped with a dual monitor display and a desktop computer. All questionnaires and assessments were administered via an online survey tool. Morae usability software was used to capture recordings of all participants' onscreen actions during the essay revision and feedback interface use.

2.2.6 Procedure

The experimental protocol took place across two sessions, varying between 1 and 13 days between sessions, averaging 7 across all participants (see Figure 7 for a visual outline of the protocol). In session 1, participants completed an informed consent procedure and were randomly assigned to a condition. Next, participants completed the prior knowledge assessments, the true/false assessment, and then the short answer application assessment. Next, participants were asked to use the learning materials to learn as much about weather and climate as they could for 30 minutes. Participants were not allowed to move on to the next task early. After 30 minutes, the learning materials were closed and the participant was presented with a blank Microsoft Word document that contained the essay prompt at the top. Participants were given 25 minutes to write an essay. Finally, learners completed the learning assessment posttests: the true/false questions and the short answer application questions. At the end of Session 1, a return session was scheduled with the experimenter for the following week.

In Session 2, participants were presented with their draft essay from Session 1 in the essay revision interface and provided with the following introduction:

Today you are going to make revisions to your draft essay that you wrote in session one. Offline, we had a computer program read your draft essay. The program highlighted sentences it thought needed attention and also provided prompts to encourage you to think deeply about the content contained in the essay. The computer system analyzed all of the web materials that it could about your topic and it tried to determine what problems might be in your essay and how the information you've included fits into the overall topic. While it was reading the online resources, it selected a few where you could find more information.

Participants then received instructions relevant to their experimental condition:

- Instructions for no foundational knowledge scaffold + graphical organizer: *The system provided a visual of the topic overview for weather and climate. The highlighted nodes are topics where the systems thought there may a misconception in your essay. Click on the highlighted nodes to see where the error is and resource recommendations.*
- Instructions for foundational knowledge scaffold + graphical organizer: Participants in this condition received the above graphical organizer instructions plus "*In the diagram, the importance of the idea to the topic is indicated by the size of the circle. Key ideas appear bigger than details or supporting ideas.*"
- Instructions for no foundational knowledge scaffold + text list: "*The system provides a list of topics where it thought there may be a misconception in your essay. Click on the concept to see where the errors are and resource recommendations.*"
- Instructions for foundational knowledge scaffold + text list: Participants in this condition received the introductory instructions plus "*In this list, under each concept, is a prioritized list of errors and recommended*

resources. The most critical misconceptions or errors relating to weather and climate will be at the top of the list. Similarly, the resources in which the computer program has the highest confidence of containing relevant information will appear closer to the top."

After reading the instructions, participants were asked to use the essay revision interface for 30 minutes as they made revisions to their essays. Posttest learning assessments were administered via the online survey tool.

2.2.7 Analysis

A value of $p = .05$ was set as alpha level for all analyses. Acceptable ranges for kurtosis and skewness were met (± 2) on all multivariate analyses.

2.3 Results

2.3.1 Learning Paths

A multivariate ANOVA (MANOVA) was used to analyze participants' movements through the domain. Independent variables were the experiment factors (foundational knowledge and conceptual coherence) and dependent variables were the number of moves between concepts made per condition, percentage of moves made using a foundational knowledge learning path, and percentage of moves made using a conceptually coherent learning path. Multivariate tests revealed main effects for the foundational knowledge factor ($F_{(3,63)} = 3.036$, $p < .01$; $\eta^2_p = .27$) and the conceptual coherence factor ($F_{(3,63)} = 3.346$, $p < .03$; $\eta^2_p = .14$). The test for an interaction was not significant ($F<1$).

LSD mean comparisons of proportion of moves along a learning path showed that, for both main effects, more moves along the intended learning path were made when the scaffold was present: In the conceptual coherence factor, the mean difference = .11 (*SE* = .055; $p = .04$) and in the foundational knowledge factor, the mean difference = .05 (*SE* = .055; $p < .01$). The mean comparisons provide evidence that the learning path scaffolds encouraged participants to make more moves along a designated learning path than the participants would have made by chance. For average number of moves and means and standard deviations, see Table 4.

2.3.2 SRL Behaviors

SRL behaviors were analyzed using a mixed-model, repeated measures ANOVA (RM-ANOVA) with the level of importance for concepts in the essay revision feedback representation (high vs. low) as the repeated factor (all students saw high-importance and low-importance concepts during study). The between-subjects factors were the foundational knowledge scaffold (present vs. not present) and the conceptual coherence scaffold (graphical organizer vs. text list). The dependent variables were the percentages of actions taken on target sentences that were coded as effective, ineffective, or skipped (no action taken).

Between-subject multivariate tests were not significant (*F*s<1), meaning that there were no main effects for the conceptual coherence factor or foundational knowledge factor and no interaction effect between the two. Within-subject multivariate tests revealed one significant interaction between the conceptual importance level and the foundational knowledge scaffold ($F_{(3,59)} = 3.57$, $p < .02$; $\eta^2_p = .15$). The other multivariate tests for level of conceptual importance main effect, conceptual importance and conceptual coherence scaffold interaction, and the three-way interaction between concept importance, conceptual coherence scaffold, and foundational knowledge scaffold were not significant (*F*s<1).

Univariate tests for the interaction between importance of concept levels and foundational knowledge scaffolds revealed a significant difference between groups on the percentage of effective strategies used during essay revisions ($F_{(3,59)} = 5.38$, $p < .02$; $\eta^2_p = .08$) and for percentage of sentences skipped by participants ($F_{(3,63)} = 6.10$, $p < .02$; $\eta^2_p = .09$). Participants who received the foundational knowledge scaffold (sized nodes in the graphical overview condition; prioritized list in the text condition) differed from those who did not receive cueing (see Table 5 for means and standard deviations). Participants receiving foundational knowledge scaffolds used *more* strategic SRL strategies to revise sentences of *more* important concepts (concepts designated as ‘high’) and skipped making revisions to sentences tied to less important concepts (concepts designated as ‘low’). No effect was found for percentage of ineffective strategies used during revision (*F*<1). Figure 8 shows the interaction between SRL behaviors taken on high and low importance concepts by whether or not the foundational knowledge condition was present.

These results could possibly have been a case of better students (higher knowledge participants) utilizing the learning path cues differently during the essay revision task with the essay revision interface. However, there is no evidence of prior knowledge affecting participants’ self-regulated strategies executed during the essay revision task. Two post-hoc analyses were conducted to eliminate this potential explanation: a bivariate correlation of SRL behaviors to learning outcomes and a one-way MANOVA comparing high-knowledge and low-knowledge participants' percentage of effective and ineffective strategies. No significant bivariate correlations were found between learning assessment pretests and the behaviors observed during revisions for any condition (see Table 6). A median split on the short answer application posttest from Session 1 was used to categorize higher knowledge participants and lower knowledge participants. Prior knowledge then was used as the independent variable in the one-way MANOVA; dependent variables were the percentages of effective and ineffective strategies observed during revision. No significant differences (*F*s < 1) were found.

2.3.3 Learning Outcomes

2.3.3.1 True/False Questions

An RM-ANOVA was used to compare performance on true/false questions across the three test times during the experiment. The RM-ANOVA demonstrated a main effect for test time ($F_{(2,68)} = 124.38$, $p < .01$; $\eta_p^2 = .64$) such that participants' scores improved over time (see Table 7). No main effects or interactions were found for experimental factors (*F*s < 1). The experimental conditions did not influence their factual learning (see Table 8 for means and standard deviations).

2.3.3.2 Short Answer Application Questions

Both short answer application rubric scores were analyzed using separate RM-ANOVAs. The RM-ANOVA for conceptual explanation scores, where test time (session one pretest, session one posttest, and session two posttest) was the repeated factor, revealed a main effect for time ($F_{(2,68)} = 13.16$, $p < .01$; $\eta^2_p = .16$) such that, on average, participants' quality of explanation scores improved over time. A trend for an interaction between time and the foundational knowledge cue ($F_{(1,69)} = 3.28$, $p = .07$; $\eta^2_p = .05$) also was found such that participants who did not receive foundational knowledge cues had higher average scores than those who did (see Table 8 for means and standard deviations). With regard to the idea units scores, a RM-ANOVA (test time being the repeated factor and percent of correct idea units the dependent variable) demonstrated a main effect for time ($F_{(2,68)} = 13.83$, $p < .01$; $\eta^2_p = .29$). Participants' idea unit scores improved over test time (see Table 8 for means and standard deviations). A trend for an interaction between test time and the foundational knowledge factor was also found for idea unit scores ($F_{(2,68)} = 3.14$, $p = .05$; $\eta^2_p = .09$). Participants who received the foundational knowledge scaffold generated fewer relevant idea units on the short answer application assessment (see Table 8, Short Answer Application (Idea Unit Rubric)).

For the short answer application assessment, the average score on the conceptual explanation rubric was 1.75 -- between an irrelevant answer (1 point on the conceptual explanation rubric) and a vague or incomplete answer (2 points on the rubric). The average score on the idea unit rubric was 34% coverage of relevant idea units. Low averages on both rubrics could be indicative of a floor effect with the assessment. Although time effects were found and trends for interactions with the foundational knowledge cues also are present, participants overall performed poorly on short answer application questions.

Bivariate correlations investigated the impact of moving through the domain using a learning path on learning outcomes. Correlations revealed no statistically significant relationships between using a learning path and learning outcome scores (see

Table 8 for correlations).

2.3.3.3 SRL Behaviors on Learning Outcomes

Bivariate correlations were also used to investigate the impact of SRL behaviors during study on learning outcomes. Correlations revealed no statistically significant relationships between executing effective or ineffective SRL strategies during essay revision and learning outcome scores (see Table 9 for correlations).

2.4 Experiment 1 Discussion

Experiment 1 examined the impact of scaffolds targeting conceptual coherence (text list vs. graphical organizer) and a foundational knowledge scaffold (no cues vs. domain centrality cues) on participants' learning paths, SRL strategy use, and, ultimately, learning outcomes.

To what extent did a conceptually coherent learning path scaffold affect learning path selection, SRL strategies, and learning outcomes? Experiment 1 found that participants navigated across online resources following a conceptually coherent learning path more often when they had a conceptual coherence scaffold (the graphical organizer). Thus, the hypothesis that learners can make use of conceptually coherent learning path scaffolds during an online SRL task by navigating through the domain in a semantically related manner was supported. However, it is important to note that when the participants decided which concept to address next, participants chose the next closest linked concept only a little over half of the time. The average number of moves between concepts following the conceptually coherent path was 63% whereas chance selection is 50%. While participants are able to navigate along a learning path, it seems that they only choose to do so on occasion rather than follow the learning path for the entirety of the learning task.

No evidence was found indicating that a conceptual coherence scaffold affected SRL behaviors. The SRL behaviors RM-ANOVA found no differences in the frequency of effective or ineffective SRL strategy execution on high- or low-importance concepts based on the presence or absence of a conceptual coherence scaffold. At the same time, the scaffold did not appear to deter participants from executing effective SRL strategies: Participants who received the conceptual coherence scaffold (graphic organizer) used just as many effective strategies as participants who received the foundational knowledge scaffold (see the means of effective strategies used by condition in Table 6). Without the foundational knowledge scaffold present in the graphical organizer, participants applied effective strategies to both high- and low-importance concepts rather than strategically focusing on high-importance concepts (as participants in the foundational knowledge scaffold did).

Although participants' scores improved over time, learning outcomes were not impacted by the presence of a conceptual coherence scaffold nor by the frequency with which a participant navigated the domain along the conceptually coherent path. The hypothesis that a conceptually coherent scaffold would promote deeper understanding and improved scores on the short answer application test was not supported.

To what extent did a foundational knowledge learning path scaffold affect learning path selection, SRL strategies, and learning outcomes? Experiment 1 found that participants navigated the domain along a foundational knowledge learning path more often when they had foundational knowledge scaffolds during the online SRL task.

However, just like the conceptual coherence factor, the average number of movements between concepts following a foundational knowledge sequence occurred only 63% of the time (see Table 5 for the similarity in number of moves between concepts within each condition). The more frequent use of a learning path through the domain indicates that learners can make use of the scaffold, but only choose to do so about two-thirds of the time during an online SRL task.

When foundational knowledge cues were present, participants executed more effective SRL strategies on concepts cued as more central to the domain and skipped taking action on concepts cued as less central. These interactions provide evidence that learners can make use of a foundational learning path scaffold to strategically plan their actions during an online SRL task by directing more focus and effort on concepts that provide a foundational understanding of a domain. This result supports hypothesis 2, which predicted that when learners were presented with information on more important versus less important concepts for study, they would execute more SRL effort on concepts presented as more important.

On the learning outcome measures, participants improved their scores across the sessions regardless if they were presented with the foundational knowledge scaffold or not and regardless of whether or not they followed the foundational learning path. Analysis of learning outcomes by condition and correlation of learning outcomes with behavioral measures provided no statistically significant evidence that knowing which concepts are more central to understanding a domain or navigating via a foundational learning path positively affected factual knowledge outcomes or the conceptual understanding. However, nonsignificant trends were found such that being presented the foundational knowledge scaffold negatively impacted both factual knowledge and conceptual understanding outcomes. Participants who received foundational knowledge cues were more strategic during learning, but using the scaffold to complete the revision task may have distracted the participants from the domain content.

2.4.1 Further Investigating the Learning Paths

Results from Experiment 1 highlight two unanswered questions: (1) When learners are engaged in SRL with online resources, which learning path is more optimal (one based on conceptual coherence or one based on foundational knowledge)?; (2) Will learners benefit from more strict learning path guidance during SRL with online resources? These questions are discussed in more depth below.

2.4.1.1 Which Learning Path Is More Optimal in an Online SRL Task?

Both learning paths were predicted to impact learning outcomes in Experiment 1; however, use of learning paths (regardless of type) did not influence participants' development of factual or conceptual understanding. There are three possible explanations for this. First, participants may not have followed enough of a learning path to realize predicted knowledge building processes. In both factors, learning path usage was at 63%. While use of particular learning path was higher when the corresponding scaffolds were present, it certainly was not being followed during the entire learning task. This potential problem raises the question of whether outcomes will be influenced by learning paths if participants follow them more consistently.

Second, the conceptual understanding assessments may not have been sensitive enough to detect learning outcome effects. Short answer application questions, used to measure conceptual understanding, had low average scores for all conditions.

The third possibility for null effects of conceptual coherence and mixed results on foundational knowledge cues is that highlighting only problematic concepts and allowing navigation only to these problematic concepts could have encouraged a disjointed or fragmented understanding of the domain. As seen in Figure 9, if a learner was presented with feedback on concepts that were distantly connected, then the learner had to jump from one side of the domain graphical organizer to the other to address all of the concepts. Although moving between disparate concepts could produce some desirable difficulty (by motivating learners to connect domain ideas that are not easily integrated), it also could be too difficult for the learner and lead to shallow processing focused on nodes (and not the domain). Indeed, the RM-ANOVA for conceptual understanding assessments (short answer application questions) revealed a trend for foundational knowledge cues negatively impacting scores for factual and conceptual knowledge. Learners may need additional guidance to attend to coherent relationships within a domain.

2.4.1.2 Will Learners Benefit From More Strict Learning Path Guidance During SRL With Online Resources?

As seen in Table 4, learners in Experiment 1 made few transitions between concepts in the control condition (text list and no foundational knowledge cues), but the number of transitions between concepts increased with the presentation of learning path scaffolds. The number of transitions made between concepts could be indicative of integrative knowledge building. Butcher and Sumner (2011) found that frequent switching between resources and conceptual feedback in an earlier version of the CLICK system correlated with deep essay revisions, indicating generation of new knowledge and integration with prior knowledge. Learning path scaffolds in Experiment 1 supported learners in this iterative process but perhaps not often enough to synthesize concepts across the domain into a coherent understanding. Indeed, Experiment 1 true/false scores improved after the use of the feedback interface but not the short answer scores, further supporting the hypothesis that participants gleaned facts about the domain but did not activate deeper learning processes. Much like conducting online SRL with a human tutor or ITS (Azevedo et al., 2007; Azevedo, Cromley, & Seibert, 2004; Graesser et al., 2004; Koedinger et al., 1997), learners may benefit from stronger navigational guidance along a specified learning path. That is, learners' navigational choices may need to be limited to the set of options that adhere to an assigned learning path in order to determine its potential value to SRL with online resources.

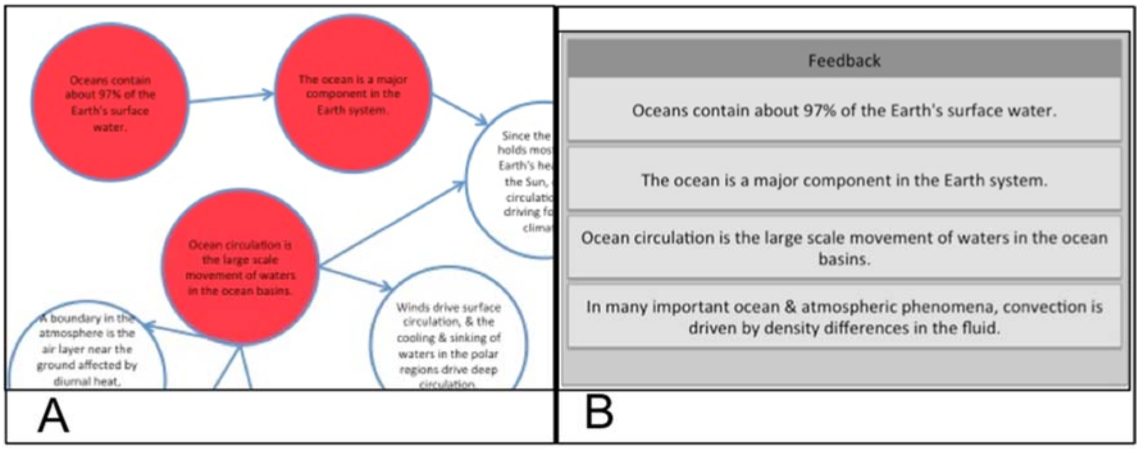

Figure 3. Conceptual coherence scaffold in the form of a graphical organizer (left, a) and text list (right, b) feedback in Experiment 1.

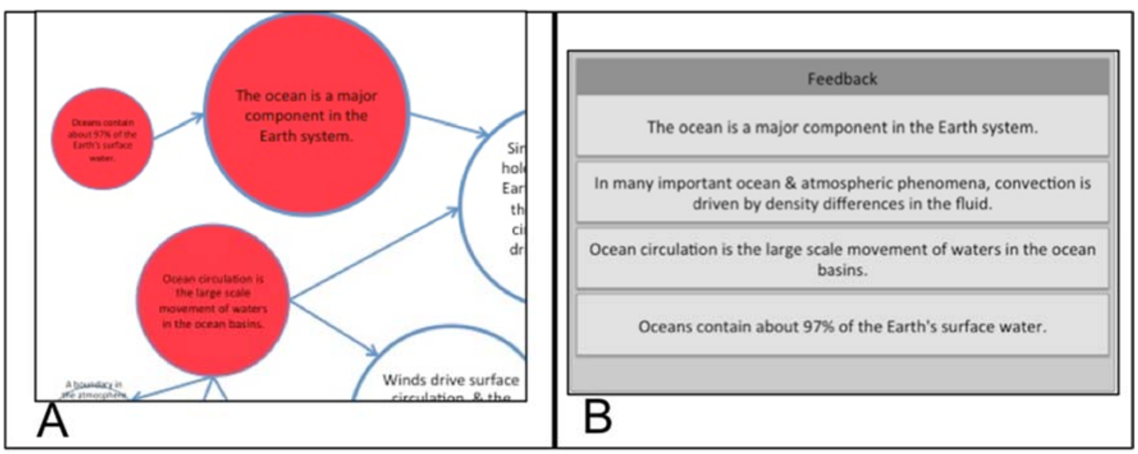

Figure 4. Foundational knowledge scaffold using visual cues (left, a) and prioritized text list (right, b) conditional feedback in Experiment 1.

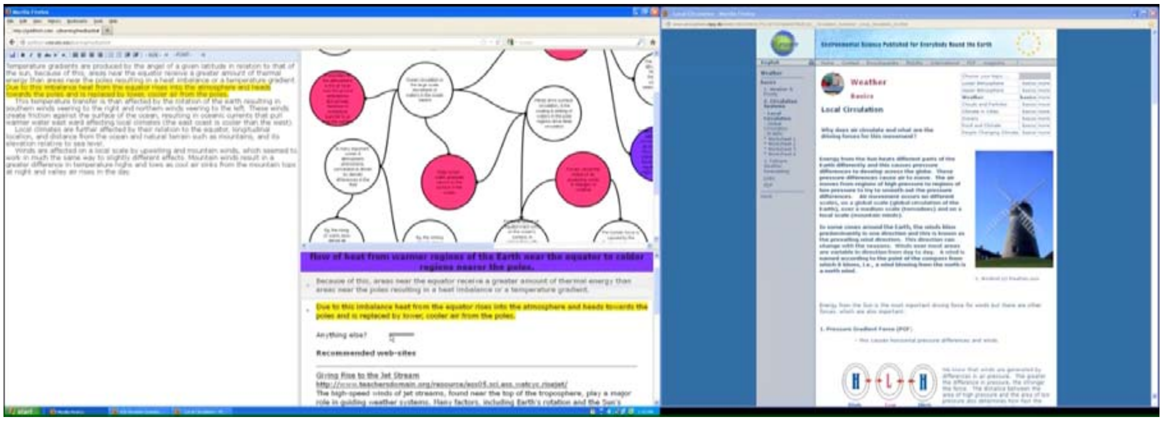

Figure 5. Screen capture of Experiment 1 essay revision interface. The monitor on the left shows the essay revision and experimental feedback. The monitor on the right shows an online resource accessible from the feedback interface.

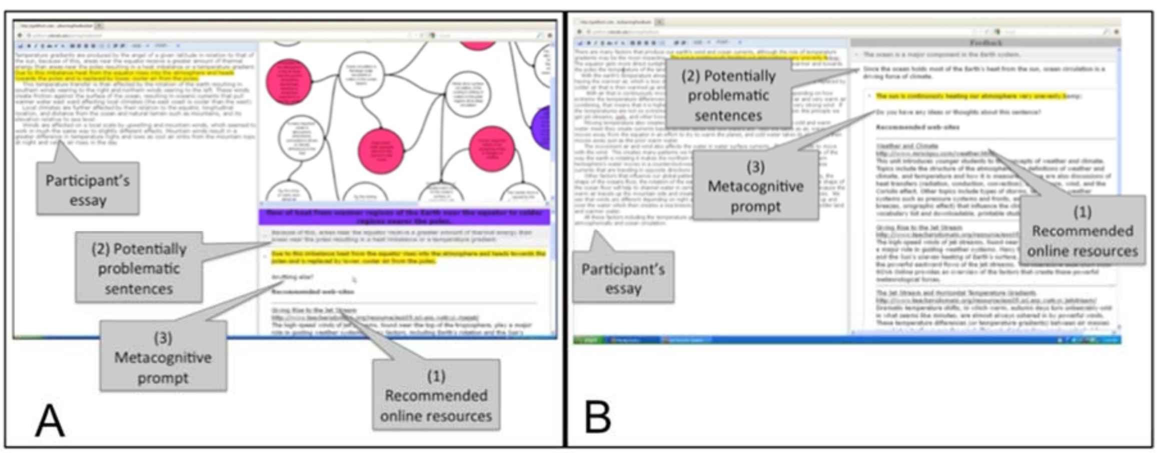

Figure 6. Two screenshots of the essay revision interface with annotations of interface elements.

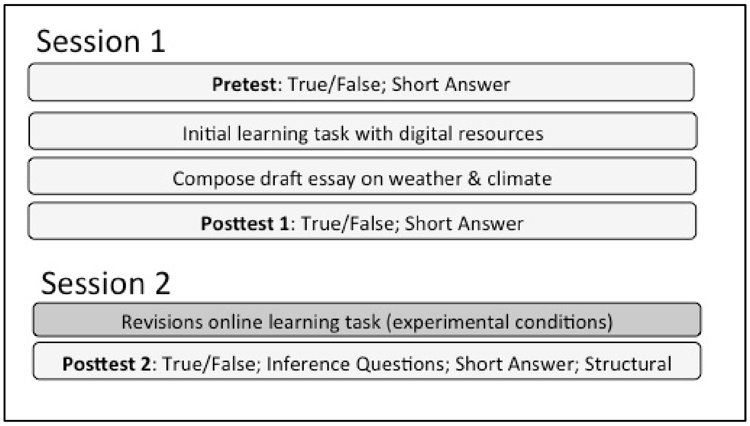

Figure 7. An outline of the Experiment 1 protocol.

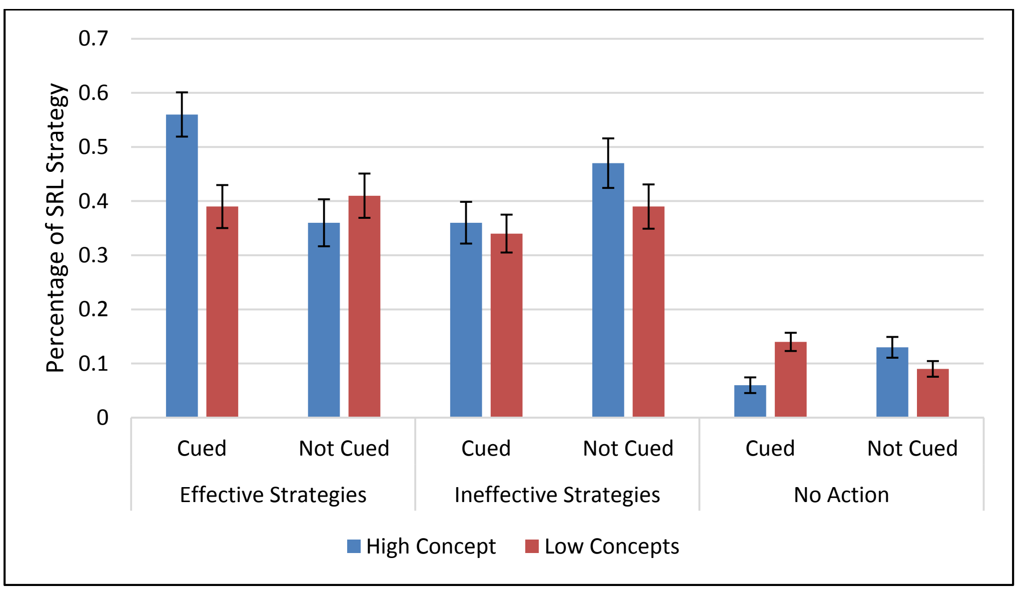

Figure 8. Percentage of SRL strategies by foundational knowledge scaffold condition (cued vs. not cued), collapsed across conceptual coherence factor.

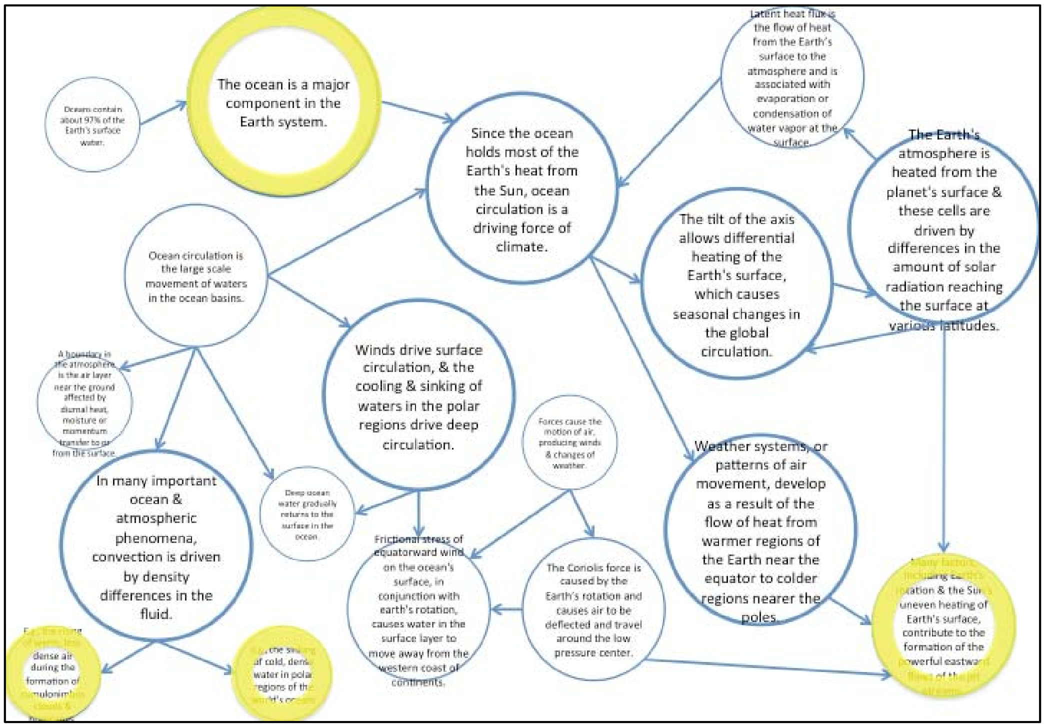

Figure 9. Participant 29b's revision interface with problematic concepts outlined.

Table 1

Description of Experimental Conditions

		Conceptual Coherence Scaffold: Text List	Conceptual Coherence Scaffold: Graphical Organizer
Foundational Knowledge Scaffold	Not Cued	Concepts presented in a list format + List is a randomized order of concepts (n=20)	Concepts presented in a node-link diagram + Graphical organizer has equally sized nodes for all concepts (n=20)
	Cued	Concepts presented in a list format + List prioritizes more important concepts in the domain at the top and less important concepts further down) (n=16)	Concepts presented in a node-link diagram + Graphical organizer has larger nodes for more important concepts and smaller nodes for less important concepts (n=17)

Table 2

SRL Behaviors Observed During Essay Revision

Observed Behavior in Essay Revision	Behavior Strategy Code
Synthesizing concept(s) from the online resources	Effective
Generating a hypothesis about the weather and climate domain	Effective
Integrating new information from an online resource with prior knowledge	Effective
Copying and pasting exact information from an online resource or the conceptual feedback	Ineffective
Editing sentence structure or wording without adjusting the underlying concept	Ineffective
Deleting the highlighted sentence with no additional integration or replacement elsewhere in the essay	Ineffective
No observable action taken for the sentence	Skipped

Table 3

Learning Path Rubric

Scaffold	Next Concept Selected	Description
Foundational Knowledge	Selected concepts in order of domain importance	Participant selected the next concept in the feedback interface that was the next most central to the domain, addressing concepts that were *more* central first before moving to concepts cued as *less* central
	Moved to a lower priority concept without addressing higher priority ones first	Participant selected a *less* central concept next when there were *more* central concepts left to address
Conceptual Coherence	Moved to a directly linked or next closest linked concept	Participant selected the next nearest concept along a node-link path depicted in the graphical organizer
	Move to a concept that had no direct or indirect links	Participant selected a concept not directly linked in the graphical organizer or did not address the next closest concept

Table 4

Movements Following a Learning Path

	Average Number of Moves Between Concepts	Percentage of Moves Following the Foundational Knowledge Learning Path	Percentage of Moves Following the Conceptual Coherence Learning Path
Text List + No Order of Concepts	6.0	.56 (.20)	.59 (.28)
Text List + Prioritized Concepts	7.5	.76 (.22)	.56 (.21)
Graphical Organizer + Equal Size Nodes	7.4	.53 (.16)	.62 (.21)
Graphical Organizer + Scaled Node Size	8.3	.68 (.19)	.76 (.19)

Table 5
Means and Standard Deviations for SRL Behaviors During Essay Revision

	Percentage of Effective Strategies		Percentage of Ineffective Strategies		Percentage of Skipped Sentences	
	High	Low	High	Low	High	Low
Text List + No Order of Concepts	.31 (.35)	.30 (.33)	.53 (.40)	.40 (.38)	.14 (.17)	.09 (.11)
Text List + Prioritized Concepts	.54 (.30)	.33 (.34)	.44 (.30)	.34 (.32)	.06 (.10)	.06 (.12)
Graphical Organizer + Equal Size Nodes	.40 (.36)	.52 (.31)	.40 (.36)	.38 (.29)	.11 (.14)	.09 (.11)
Graphical Organizer + Scaled Node Size	.58 (.38)	.45 (.32)	.29 (.33)	.34 (.27)	.07 (.14)	.17 (.15)

Table 6
Correlations of Learning Assessment Pretest Scores and SRL Strategies

	Percentage of Effective Strategies		Percentage of Ineffective Strategies	
	High	Low	High	Low
True/False Scores	.058	.019	-.096	-.006
Short Answer Application Scores	-.105	-.159	-.099	.018

Table 7

Means and Standard Deviations for Learning Outcomes

Condition	True/False % Correct			Short Answer Application (Idea Unit Rubric) % Correct			Short Answer Application (Conceptual Rubric) % Correct		
	Session 1 Pretest	Session 1 Posttest	Session 2 Posttest	Session 1 Pretest	Session 1 Posttest	Session 2 Posttest	Session 1 Pretest	Session 1 Posttest	Session 2 Posttest
Text List + No Order of Concepts	.52 (.07)	.52 (.09)	.70 (.11)	.09 (.10)	.17 (.15)	.18 (.13)	.27 (.11)	.41 (.14)	.39 (.14)
Text List + Prioritized Concepts	.50 (.09)	.50 (.08)	.75 (.10)	.10 (.09)	.19 (.17)	.14 (.15)	.29 (.15)	.37 (.15)	.33 (.15)
Graphical Organizer + Equal Size Nodes	.50 (.06)	.53 (.08)	.71 (.10)	.07 (.07)	.13 (.09)	.13 (.09)	.23 (.15)	.31 (.14)	.31 (.17)
Graphical Organizer + Scaled Node Size	.50 (.05)	.50 (.06)	.67 (.13)	.06 (.08)	.08 (.08)	.05 (.05)	.24 (.16)	.30 (.16)	.28 (.11)

Table 8

Correlations of Learning Path Movements and SRL Behaviors on Session 2 Posttest Learning Outcomes

	True/False % Correct	Short Answer Application (Idea Unit Rubric) % Correct	Short Answer Application (Conceptual Rubric) % Correct
Use of Conceptual Coherence Learning Path	-.176	-.021	.079
Use of Foundational Knowledge Learning Path	-.111	-.027	-.003
% Effective SRL Revisions	-.502	-.143	-.223
% Ineffective SRL Revisions	-.123	-.084	-.110

CHAPTER 3

EXPERIMENT 2

Experiment 2 was designed to explore the impact of learning paths under varying levels of learner control in an SRL task with digital resources. In Experiment 2, type of learning path (conceptual coherence vs. foundational knowledge) served as one factor that was implemented within the weather and climate graphical organizer for all conditions in this study. Because the graphical organizer had no negative impact on participant learning path selection, SRL behavior, or learning outcomes in Experiment 1, it is reasonable to expect that learners are able to work with a graphical organizer just as well as a text list. In addition, the graphical organizer provides a better and more accurate representation of conceptual connections within the domain than can be achieved with a text list representation. Finally, graphical organizers are theorized to serve as a foundation for future knowledge integration for novice learners (Mayer, 1979; O'Donnell et al., 2002) and may serve as a progress indicator during SRL (Hagemans, van der Meij, & de Jong, 2013; Hofer, Yu, & Pintrich, 1998).

The second factor in Experiment 2, learner control, explored the level of learner control allowed as learners navigated online resources during an SRL task. In the learner choice condition, participants were given a choice of which concept to address next, but choices were limited to the set of appropriate options based upon the assigned learning path. In the system-directed condition, learners were directed to the next appropriate concept according to their assigned learning path when navigational decisions needed to be made.

Limiting navigation to a specific choice and decision point for learners in the learner-choice condition could prove to become a point of frustration during an online SRL task. Prior research in the human-computer interaction field has theorized a potential risk of frustration when control is limited within an environment or tool, potentially leading to limited or little usage, even when the tool or environment is beneficial in assisting the user to attain his or her goals (Cho, Cheng, & Lai, 2009; Mathieson, 1991). To capture any potentially perceived loss of usefulness due to limiting the control a learner has in determining his/her path through the domain, a perceptions survey was included in Experiment 2 that captured ratings on perceived utility of the environment and value of controlling the environment during learning.

Unlike Experiment 1, learners in Experiment 2 utilized the prescribed learning path 100% of the time because both conditions required students to navigate in a manner that was consistent with a specific learning path. Even in the leaner-choice condition, navigational options were limited to the set of choices relevant to the specified learning path. Experiment 2 was designed to investigate the extent to which level of learner control within restricted guidance (learner-choice v. system-directed) through the learning path was helpful to learners yet still retain the potential benefits of self-directed learning processes. It is important to note that in both conditions, significant SRL decisions remained under the control of the learner, including which suggested resources to visit, the amount of time spent using an online resource, and the depth with which it was processed. However, only students in the learner-choice condition were faced with navigational decisions in the domain map during the online SRL task.

In Experiment 1, learners were only exposed to the conditional environment during essay revisions in Session 2, resulting in only 30 minutes of being exposed to the domain macrostructure (if the participant was part of the conceptual coherence conditions) or importance of concepts (if the participant was part of the foundational knowledge conditions). To maximize exposure to the domain materials according to experimental condition, in Experiment 2, participants studied with their conditional learning environment in Session 1. This resulted in a double-dosage of exposure to the learning path and learner control treatments in Experiment 2 compared to Experiment 1.

3.1 Research Questions and Hypotheses

Experiment 2 examined key questions arising from Experiment 1 using a dynamic scaffold to structure learning paths through domain content under varying levels of learner control.

1. How do the foundational knowledge versus conceptual coherence learning paths affect learning outcomes when system functionality requires them to be used in an online SRL environment?

Hypothesis 1. Following a learning path based on conceptual coherence will result in the development of coherent understanding and better conceptual knowledge compared to a learning path based on foundational knowledge structures. Participants in the conceptual coherence condition were expected to score higher on deeper learning assessments than participants in the foundational knowledge condition.

2. To what extent does self-determined vs. system-determined movement through a prescribed learning path influence SRL strategies and learning outcomes?

Hypothesis 2. Learners exerting choice over their next conceptual target were predicted to show more positive learning outcomes than learners who were system-directed. In Experiment 1, learners did not stay on a learning path through the entire learning task, which may have negatively impacted their emerging understanding. Constrained learner-choice in this experiment may serve as the balance between complete SRL direction (being able to choose which concept is next to address) and externally directed navigation along a learning path. In the system-directed condition, self-directed SRL processes (like monitoring and strategizing) were predicted to decrease, also decreasing the use of effective SRL strategies and leading to lower learning outcomes.

3.2 Methods

3.2.1 Design

Experiment 2 utilized a 2x2 factorial design. Independent variables were (1) guidance (system-directed vs. learner-choice) and (2) learning path (foundational knowledge vs. conceptual coherence). Table 9 describes the four experimental conditions.

3.2.2 Participants

Participants were recruited from the University of Utah Educational Psychology research participation pool. Sixty-nine participants were recruited for the experiment. Four participants did not return to the second session and one participant experienced technical difficulties with the essay revision environment during Session 2, resulting in an incomplete learning task. This resulted in a sample of 64 participants (50 females, 14 males). Table 9 lists the number of participants per condition.

3.2.3 Materials

Learning assessments remained the same as Experiment 1 but included two additional measures: a structural knowledge assessment and inference questions. A survey on perceptions of utility and control with the online environment also was added. The essay revision interface was presented in a graphical organizer format and was modified from Experiment 1 in order to support system-directed and learner-choice navigation. Due to practical constraints in processing texts, CLICK identification of problematic sentences was simulated by hand-selection of essay sentences to address during revision. The revision interface also was modified to remove the essay writing pane for Session 1; in Session 2, the revision interface was the same as the one used in Experiment 1.

3.2.3.1 Structural Knowledge Assessment

This assessment measured the extent to which a participant learned connections between concepts during study. The concepts from the graphical organizer were presented in nodes without any relationship links connecting them. Participants were asked to draw the links and write an explanation for each link that they draw (see Figure 10). Links were evaluated by counting the number of correctly drawn links (lines only) and by counting the number of correct directional arrows (the placement of the arrowhead on a line) indicating causality between nodes. There was a maximum score of 23 correct lines and 23 correct arrows. Incorrect links also were tallied, but incorrect directional arrows were not (since incorrectly linked nodes do not have a causal relationship, the arrowheads are meaningless for incorrect links).

3.2.3.2 Inference Questions

Inference questions were used to assess deep learning (in addition to the short answer application questions). These questions targeted near transfer of knowledge for which integration of two or three concepts would be required to answer. The questions were derived from the existing true/false questions to ensure content validity. For example, this question: *How does the energy stored in the ocean drive climate around the Earth?* built on the true/false question *Thermal energy is transferred around the earth by the movement of air in the atmosphere but not the movement of ocean water.* and required a combined understanding of three domain concepts presented in the domain graphical overview: *Since the ocean holds most of the Earth's heat from the sun, ocean circulation is a driving force of climate*, *Latent heat flux is the flow of heat from the Earth's surface to the atmosphere and is associated with evaporation or condensation of water vapor at the surface*, and *The ocean is a major component in the Earth system.* A common process in all of three of the domain concepts listed is thermal energy. Thus, identifying the correct idea in the submitted explanation, such as “thermal energy,” received full credit for the participant response. Five questions were used for this assessment, each worth one point, resulting in five total points possible.

3.2.3.3 Survey on Perceptions of Utility and Control

Perceptions of utility and control were captured in a 16 Likert scale item survey. Participants selected their agreement with statements on a scale of 1 to 5, with 1 being “strongly agree” and 5 being “strongly disagree.” Questions of utility focused on how effective or useful to learning the online environment was to participants. For example, “I feel like I gained a coherent understanding of ideas in weather and climate.” Questions of control focused on how learners perceived aspects of learner choice and self-directed decision making. For example, “The tool restricted my choice too much during revisions.”

3.2.3.4 Essay Revision Interface

Graphical organizer scaffolds remained the same for the learning paths in Experiment 2 as in Experiment 1. All participants saw the explicit connections between concepts in the graphical organizer as well as the size-scaled nodes that indicated conceptual importance within the domain.

For participants in the learner-choice condition, the system activated the set of all node concepts consistent with the learning path to which the learner could navigate. This allowed participants a level of choice in navigation, but constrained their decision to the subset of concepts consistent with their assigned learning path (see Figure 11). For the foundational knowledge learning path, this meant that students could choose any of the nodes that were at the same level of informational importance when navigating away from a node. For example, when a student in the learner-choice foundational knowledge condition began working with the graphic organizer, all high-importance concepts were active and could be clicked in the graphical organizer (Figure 11a). The student could not select a lower priority concept until they had clicked on all high-priority concepts first. In contrast, a learner in the learner-choice conceptual coherence condition could only choose from the directly linked nodes to the current node. At times, this meant that learners has multiple choices of nodes, but there was only one directly linked node in some cases (see Figure 11b).

For participants in the system-directed conditions, only one concept on the graphical organizer was active for the participant to click at any given time, eliminating the choice in which concept to address next and restricting movement through the domain to the assigned learning path. Once the participant was ready to move on from a node, she clicked on a button that took her to the next system-directed concept (see Figure 12 for an example).

For participants in the system-directed foundational knowledge condition, only the next highest priority concept was active, allowing them to click on it for further research and/or essay revisions. If the foundational knowledge learning path is effective, then the order of which more important concepts are learned first should be not as important as learning them before moving onto less important concepts. Thus, in order to maximize differences between the learning path conditions, the highest priority concept farthest away from the current node was activated next. As seen in Figure 12a, a participant working on a high-priority node in the top left of the screen would then be directed to a distant high-priority node. For participants in the system-directed conceptual coherence condition, the next directly linked node, moving left to right, top to bottom, was activated next. That meant that the small node to the left (the outlined node in Figure 12b) would be the starting point, because it was the most left concept near the top of the graphical organizer. Once the participant finished with the small node, then the large white node to the right would be the next node to become active.

It is important to note that across all conditions, participants retained the ability to execute SRL behaviors based on their own judgments. Although adherence to the experimental learning path was forced within the environmental design, participants still dictated how long they spent on each concept, how they addressed any essay revisions associated with a concept, and, in the case of the learner-controlled conditions, were able to choose to revisit nodes or which node of a subset that were available to navigate to next. Of 23 conceptual connections within the graphical organizer, only 4 concepts had single connections, which limited the choice learners could take in the conceptual coherence knowledge path. Thus participants in the learner-choice, conceptual coherence condition had an average of 3 concepts to choose from next, and for each concept between 2 and 3 relevant resources. Participants in the learner-choice foundational knowledge condition had an average of 5 concepts to choose from next, and for each concept between 2 and 3 relevant resources. Participants in the system-directed conditions were not given a choice of which concept to navigate to next, but did retain the choice of how (or if) to use the 2 to 3 relevant resources for each concept chosen for them. Once a resource was selected, both conditions had equivalent SRL demands that included how long they used the resource and the depth to which they processed it.

3.2.4 Procedure

Participants were recruited for two sessions, just as in Experiment 1 (see Figure 13 for an outline of the Experiment 2 session procedures). Time between sessions varied between 1 and 14 days, averaging 4 days across all participants. Participants began Session 1 with 15 minutes to complete the knowledge pretests: true/false (5 minutes time limit), inference (5 minutes limit), and short answer applications questions (5 minutes limit). Participants then spent 30 minutes engaged in SRL with the online resources using the experimental condition that was randomly assigned to them upon entering the study.

Participants were provided with the following introduction to the SRL task:

> *This system contains several resources with information about weather and climate. The large graphic on your screen is a concept map of ideas within the weather and climate knowledge domain. Each circle is a concept node, and the key idea is labeled in the circle. The lines between concepts represent a conceptual relationship between the ideas. You will notice that there are three different sizes of concept nodes in the graphic; the largest size [point to an example on the participant's monitor] indicates a key idea within the domain, the medium size [point to an example on the participant's monitor] is a subtopic of the domain, and the smallest size [point to an example on the participant's monitor] indicates a detail or example of phenomena within the domain. Each concept [click on the first concept relevant to the condition to demonstrate] contains a list of recommended online websites with further information and detail about the concept. Visit these resources and focus reaching a deep understanding of each concept before moving on to the next one.*

Participants then received instructions relevant to their experimental condition:

- Instructions for conceptual coherence path + learner-directed:

> *You will progress through this concept map studying directly-related concepts. You may choose any concept that has a line connecting it to the one you are currently on. In the case of only a single connection, you will only be allowed to choose that concept. You may revisit any concept nodes as long as they are directly connected.*

- Instructions for conceptual coherence path + system-directed:

You will progress through this concept map studying directly-related concepts. Beginning with this node [point to the starting point on the participant's monitor] you should study it as long as you need to reach a deep understanding of the concept. When you are ready to learn about a new concept, click the 'Continue ' button. The system will move you to the next conceptually-relevant topic to study. Once you click 'Continue', you cannot return to that node.

- Instructions for foundational knowledge path + learner-directed:

You will progress through this concept map studying the most important, key ideas first. You may choose any concept that is a large node to learn more. Once you are finished learning about all of the key ideas, you may click the 'Continue' button to learn about the subtopics in medium-sized nodes, then again to access the details in small nodes. Once you move on to a new size, you cannot return to the previous size nodes.

- Instructions for foundational knowledge path + system-directed:

You will progress through this concept map studying the most important, key ideas first. Beginning with this node [point to the starting point on the participant's monitor] you should study it as long as you need to reach a deep understanding of the concept. When you are ready to learn about a new concept, click the 'Continue ' button. The system will move you to the next most important idea in the domain to study next. Once you click 'Continue', you cannot return to that node.

Next, participants were given 15 minutes to write an essay in response to the same prompt used in Experiment 1. Participants then filled out the perceptions survey, with a time allotment of 10 minutes. Session 1 finished with the postlearning assessments consisting of true/false (5 minutes time limit), inference (10 minutes limit), structural knowledge (10 minutes limit), and short answer application questions (10 minutes time limit), allotting 35 minutes overall for completion.

Session 2 began with 30 minutes for essay revisions using the essay revision interface followed by 10 minutes to complete the perception survey. Postlearning assessments (35 minutes) consisted of true/false (5 minutes time limit), inference (10 minutes limit), structural knowledge (10 minutes limit), and short answer application questions (10 minutes limit).

3.2.5 Analysis

A value of $p = .05$ was set as alpha level for all analyses. Acceptable ranges for kurtosis and skewness were met (± 2) on all multivariate of analyses.

3.3 Results

3.3.1 SRL Behaviors

SRL behaviors (see Table 2 for a coding rubric) were analyzed using a MANOVA, the between-subjects factors were the learning path (foundational vs. coherence) and the level of control (learner-choice vs. system-directed). The dependent variables were total number of revisions made during the essay revisions task, total number of effective strategies used during essay revision, and total number of ineffective strategies used during essay revision. Multivariate effects for the experimental factors were not significant (*F*s<1) but the interaction between the factors was statistically significant ($F_{(3,58)} = 3.28$ $p = .03$; $\eta^2_p = .15$). Table 10 provides means and standard deviations for the conditions on number of revisions and number of strategy types.

Although the multivariate test for main effects was not significant, univariate tests revealed a significant effect for learning path on the number of effective strategies used ($F_{(1,60)} = 4.13$, $p = .05$; $\eta^2_p = .06$) such that participants in the conceptual coherence conditions were observed using fewer effective strategies than participants in the foundational knowledge conditions ($M = 5.03$, $SD = 4.36$; $M = 7.73$, $SD = 6.14$, respectively). Univariate tests for number of ineffective strategies and total number of revisions yielded no effect of learning path (*F*s<1). Univariate tests for level of choice yielded no main effects (*F*s<1).

Univariate tests of the significant multivariate interaction between the learning path and level of control factors revealed a trend for differences in the total number of revisions made ($F_{(1,60)} = 3.33$, $p = .07$; $\eta^2_p = .05$) but no significant differences between number of effective or ineffective strategies observed (*F*s<1). Learning path had little impact under learner-directed conditions, but made a difference in the number of revisions in the system-directed conditions. Participants in the conceptual coherence learning path who received system direction made the fewest revisions (see Figure 14). No interaction was found for the average number of effective or ineffective strategies.

3.3.2 Learning Outcomes

3.3.2.1 True/False Questions

An RM-ANOVA was used to compare performance on true/false questions between the three test times during the experiment (prelearning, postlearning Session 1, and postlearning Session 2). The RM-ANOVA demonstrated a main effect for time, such that participants in all conditions improved over time ($F_{(2,59)} = 21.48$, $p < .01$; $\eta^2_p = .28$). No main effects for learning path or level of control were found (*F*s<1). Table 12 contains means and standard deviations for the true/false assessment by condition.

3.3.2.2 Inference Questions

A RM-ANOVA was used to compare performance on inference questions between the three test times during the experiment. The RM-ANOVA demonstrated a main effect for time, such that participants in all conditions improved over time ($F_{(2,59)} = 24.37$, $p < .01$; $\eta^2_p = .29$). No main effects for learning path or level of control were found (Fs<1). Table 12 contains means and standard deviations for the inference assessment by condition.

3.3.2.3 Short Answer Application Questions

Both short answer application rubric scores (quality of explanation and number of idea units) were analyzed using separate RM-ANOVAs with test time being the repeated variable. No main effects were found for time or factor (Fs<1); however, a three-way interaction of learning path by level of control by time for percentage correct idea units was revealed ($F_{(2,58)} = 3.17$, $p = .05$; $\eta^2_p = .10$). Further analysis was conducted to identify what was driving the interaction, beginning by evaluating potential differences at pretest. A two-way ANOVA was conducted where learning path and level of control were the independent variables and pretest percent correct for idea units was the dependent variable. No significant group differences were found for pretest scores (Fs<1). Thus, the interaction effect was not driven by preexisting knowledge differences. Next, a MANOVA was conducted where learning path and level of control were the independent variables and dependent variables were the Session 1 posttest and Session 2 posttest. Results showed no main effects for the experimental factors (Fs<1) but did reveal an interaction between learning path and learner control ($F_{(2,58)} = 3.13$, $p = .05$; η^2_p

= .10). Univariate tests yielded no significant results (*F*s<1). Figure 15 shows the interaction of test time, learning path, and choice on Session 1 and Session 2 posttests.

At the end of Session 1, participants in the system-directed learning path condition seemed to have similar understanding of domain concepts regardless of the learning path that the system followed. By comparison, learners who exerted choice in which concept to study next learned more when they studied a foundational knowledge path than when learning from a conceptually coherent path. At the end of Session 2, participants learning via a foundational knowledge path with system guidance made the greatest learning gains and the potential advantage of foundational knowledge scaffold participants in the learner choice condition had disappeared at the end of Session 1.

3.3.2.4 Structural Knowledge Assessment

The planned analysis to code relationship descriptions was not conducted due to the written responses being sparse and not amenable to analysis. Instead, a repeated measures MANOVA compared the percentage of correct lines and arrows drawn on the structural knowledge assessment for both test times (at the end of Sessions 1 and 2). The multivariate test revealed a main effect for learning path ($F_{(2,58)} = 4.70$, $p = .01$; $\eta^2_p = .14$) such that participants in the foundational knowledge conditions drew roughly the same number of lines as those in the conceptual coherence condition, but they drew correct links more frequently than participants in the conceptual coherence condition (see Table 11). A within-subjects effect for time also was found ($F_{(2,58)} = 4.10$, $p = .02$; $\eta^2_p = .12$) such that learners generally improved over time. The multivariate test of the learner control factor was not significant (*F*s<1). The multivariate test of interactions revealed an interaction of test time by learning path ($F_{(1,59)} = 4.2$, $p = .05$; $\eta^2_p = .07$).

Univariate tests revealed a significant effect of time for the correct number of lines drawn ($F_{(1,59)} = 7.79$, $p < .01$; $\eta^2_p = .12$) and a trend of time on the correct number of arrows drawn ($F_{(1,59)} = 3.70$, $p = .06$; $\eta^2_p = .06$); with more exposure to the learning materials across the study, students increased the number of correctly indicated relationships. Univariate tests also revealed a trend for the arrows variable ($F_{(1,59)} = 2.81$, $p = .10$; $\eta^2_p = .05$), likely due to the foundational path participants outperforming conceptual coherence path participants.

3.3.2.5 SRL Behaviors on Learning Outcomes

Bivariate correlations investigated the impact of executing effective versus ineffective strategies during the essay revision task on learning outcomes at the end of Session 2. Correlations revealed one significant, negative correlation between the number of ineffective strategies observed and inference scores ($r = -.26$, $n = 64$, $p = .04$; see Table 12 for all correlations). Larger numbers of ineffective strategies during learning were associated with lower inference scores at the end of the experiment.

3.3.3 Perceptions of Control and Utility

A two-way MANOVA was used to analyze the perceptions survey ratings. Learning path (conceptual coherence vs. foundational knowledge) and level of learner control (learner-choice vs. system directed) served as the between-subject factors and dependent variables were the average ratings for items focused on control within the online learning system and for items focused on the utility of the online learning system. The multivariate test revealed a main effect for learner control within the system ($F_{(2,59)} =$

6.14, $p < .01$; $\eta^2_p = .17$). The main effect for learning path and tests of interactions were not significant (*F*s<1). Univariate tests revealed a significant effect on the ratings for control within the system ($F_{(1, 60)} = 12.07$, $p < .01$; $\eta^2_p = .17$); not surprisingly, participants in the learner-choice condition provided higher average ratings for feeling in control of the system than participants in the system-directed condition. The univariate test for ratings of utility were not significant (*F*<1). See Table 13 for means and standard deviations.

Bivariate correlations investigated the impact of feeling more in control of the learning experience and finding value in the experimental system on learning outcomes. Correlations revealed no statistically significant relationships between feeling more in control or finding more value in the system on learning performance (see Table 14 for correlations).

3.4 Experiment 2 Discussion

Experiment 2 examined the impact of different learning paths and the degree of learner control allowed during navigation on SRL behaviors, learning outcomes, and user perceptions within an online SRL environment. Results are discussed below.

3.4.1 How Do the Foundational Knowledge Versus Conceptual Coherence Learning Paths Affect SRL Strategies and Learning Outcomes in an Online SRL Environment?

Experiment 2 found that when participants navigated the domain along a conceptually coherent learning path, they engaged in fewer effective SRL behaviors than learners who navigated the domain along a foundational knowledge path. Furthermore, participants who saw the conceptual coherence learning path and whose navigation was restricted by the system (the conceptual coherence + system-directed condition) performed the fewest number of essay revisions during Session 2. Although learning path did not impact all outcomes, a deep learning assessment (short answer application) showed an effect across test time. Contrary to predictions, participants in the conceptual coherence path drew fewer correct directional arrows on the structural knowledge assessment, revealing that foundational knowledge path participants gained a more robust understanding of the relationships between concepts, including directionality of causal relationships.

In general, the foundational knowledge learning path seemed to provide a better knowledge framework for integration during further study. As other researchers have predicted (VanLehn, 2006; Wiggins & McTighe, 1998), a foundational framework may be more appropriate for novice learners to develop first before attempting to integrate conceptually coherent details between the big ideas. From the perspective of the CI model of text comprehension (Kintsch, 1994), a well-developed textbase representation is necessary for construction of the situation model. A foundational knowledge learning path may serve to develop a more complete and robust textbase representation during SRL with online resources, facilitating subsequent situation model development.

Another possibility is that a foundational knowledge learning path provides inherent desirable difficulty (Bjork, 1994) by motivating students to connect far-reaching ideas present within a domain graphic organizer. From this perspective, learners may be engaged in productive confusion. This possibility is discussed more fully in the general discussion.

3.4.2 To What Extent Does Self-Determined Versus System-Determined Movement Through a Learning Path Influence SRL Strategies and Learning Outcomes?

As discussed in the context of the learning path factor above, learner control interacted with the learning path to impact the number of overall revisions participants made during essay revisions. Participants in the system-directed, conceptual coherence condition produced the fewest meaningful essay revisions. However, learner control itself did not have a strong impact on revisions. No main effects for the level of control were found on the number of effective or ineffective strategies executed during the learning task.

Learner control did interact with learning path when assessing deeper understanding that participants developed, as evidenced by the short answer application assessment. At the end of Session 1, the system-directed participants performed roughly the same on application items regardless of learning path. In contrast, self-directed conditions interacted with learning paths to predict application item performance. Self-directed conceptual coherence participants showed the worst performance of the four conditions and self-directed foundational knowledge participants performed the best. Thus, during a self-directed, initial online learning task, scaffolds may be needed to support more foundational approaches to knowledge development. At the end of Session 2, the system-directed participants who followed a foundational knowledge path made the most gains, where the other three conditions performed only slightly better than the

Session 1 posttest. This may mean that extended online learning tasks can benefit from reducing navigation decisions faced by learners (and thus removing one source of processing demands during online study). However, Session 1 and Session 2 also differed in the nature of the learning task (initial learning and summarizing vs. essay revision and knowledge refinement). Thus, it is possible that optimal learner control may be determined by the nature of the online learning task being pursued by the learner. More research will be necessary to explore these possibilities.

3.4.3 How Do Learners Perceive Level of Control and Learning Path in Online Systems?

As may be expected, participants in the learner-directed conditions reported that they felt more in control of the online environment during the learning task. However, this increased level of perceived control did not correlate with better learning outcomes or more effective implementation of SRL strategies. Participants did not report a difference in perceived utility of the SRL environment based upon level of control. Taken together, one can conclude that although the system-directed participants noticed that they were constrained in their navigation along a learning path, the restriction did not undermine the perceived usefulness of the environment itself. This finding is consistent with prior literature demonstrating that users of sophisticated technology do not seem to mind having less control over the system if it is perceived as useful (Barkhuus & Dey, 2003). Overall, the average rating of utility of the online environment was 3.4 (SD = .46), which would fall slightly positive of a neutral opinion of the system. Although the tool was not perceived as highly useful for online learning, it was not perceived as a burden to learn with it either.

In general, results did not show particularly strong effects of learning path or learner control on learning outcomes and SRL behaviors; thus, potential explanations for weak effects are further explored below.

3.4.4 Were the Conditions too Similar?

All conditions in Experiment 2 received the same visual scaffolding (conceptual coherency displayed in a graphic organizer via relational links and size scaling to indicate domain importance) and the same access to digital resources via the online tool. The visual scaffolding features – both the graphical organizer and the visual cueing to represent domain importance -- have been demonstrated to be effective for novice learners when learning in complex domains (Amadieu & Salmerón, 2014; Ferrara & Butcher, 2011; O'Donnell et al., 2002). Thus, all conditions received well-designed tools that should promote domain understanding when learning with online resources; in effect, there was not an impoverished control condition in which useful scaffolding was withheld from participants in the experiment. The similarity in conditions could be one reason for weak results, and further exploration of dosage effects to investigate that are discussed next.

3.4.5 Was Exposure to the Learning Tool too Short?

To tease out potentially stronger impacts on learning outcomes or SRL behaviors, future research should investigate dosage effects beyond those included in the current research. Experiment 2 increased dosage over Experiment 1 by 30 minutes, but with conditions providing similar scaffolding and support, that increase may not have been enough to detect differences. This issue is described in more detail in the general discussion under potential limitations of the study.

3.4.6 Were the Assessments Sensitive Enough?

Although additional assessments were added to attempt to capture more specific changes in knowledge, specifically the inference questions and the structural knowledge assessment, they may not have been sensitive enough to the kinds of knowledge changes experienced by participants. An effect of time was found for the inference questions, but no main effects were found for the learning path or learner control factors. This could mean that participants were better able to infer the underlying processes that made two or three concepts conceptually related simply by studying the domain information via the graphical organizer. While the structural knowledge assessment did capture an impact on understanding the directionality of relationships between domain concepts for those in the foundational knowledge conditions, it was unexpected to find null results for identifying the basic relationship links between concepts (Experiment 2 included the prediction that conceptual coherence conditions would be able to identify more of those relationships than foundational knowledge conditions). Further implications of these results are discussed in detail.

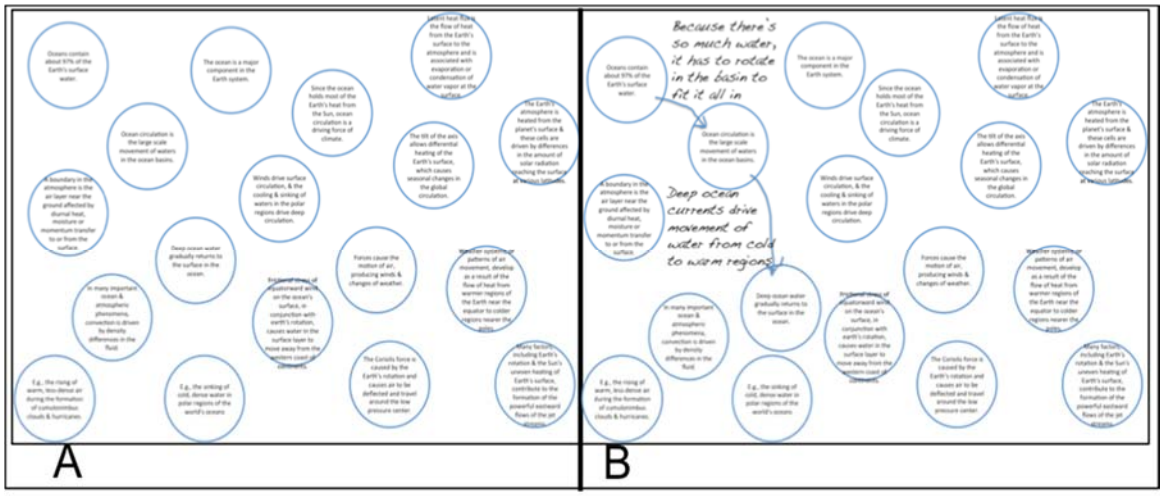

Figure 10. Example of the structural knowledge assessment given to participants (a) and sample student annotations (b).

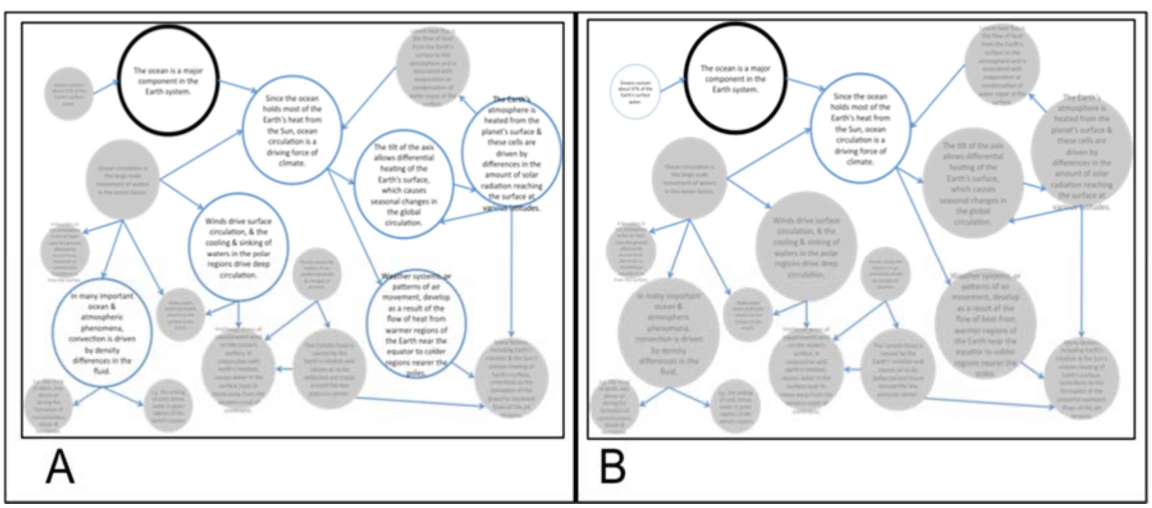

Figure 11. Navigation choices for the learner-choice, foundational knowledge condition (a) and for the learner-choice, conceptual coherence condition (b).

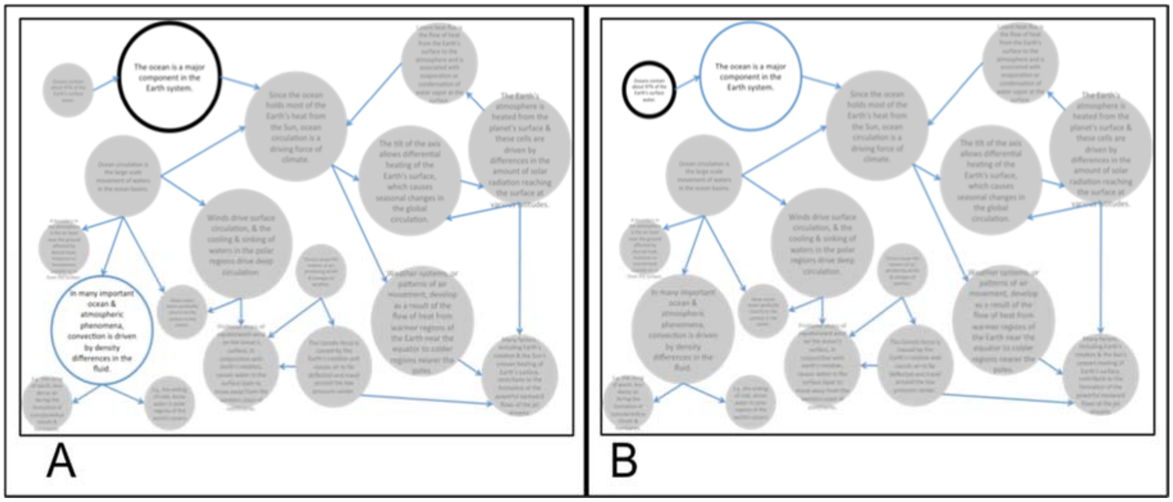

Figure 12. Navigation choices in system-directed conditions. Figure a shows the current node (outlined) and next available node (white) in the system-directed, foundational knowledge learning path condition. Figure b shows the starting node (outlined) for the system-directed, conceptual coherence condition with the next available concept (white).

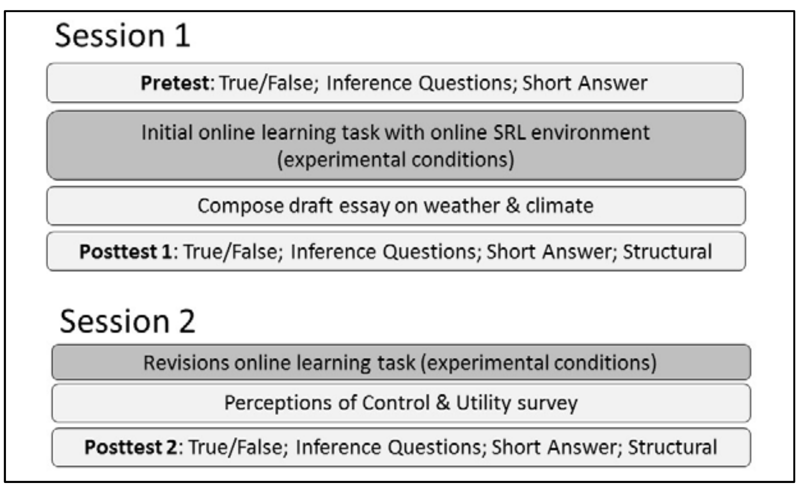

Figure 13. An outline of the Experiment 2 protocol.

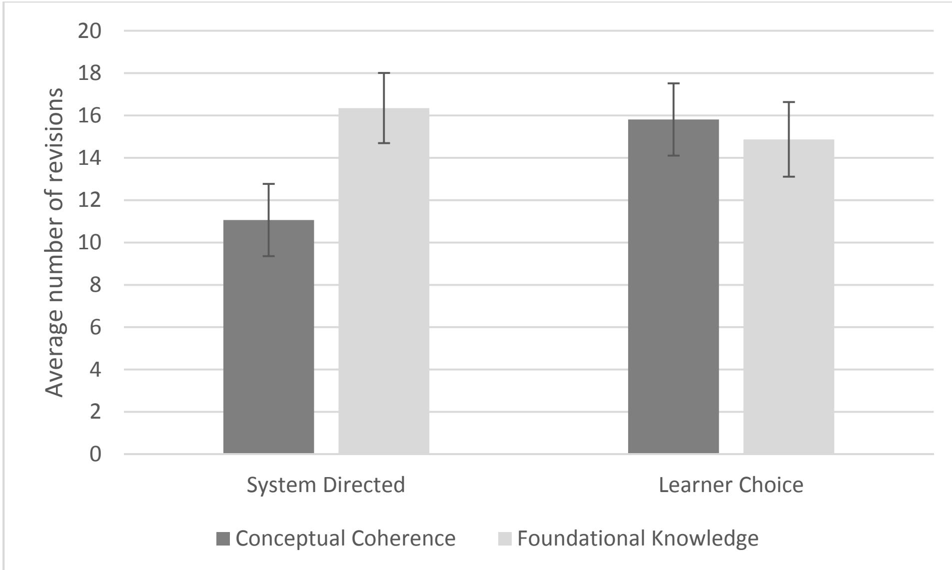

Figure 14. Average number of revisions made by learning path and learner control.

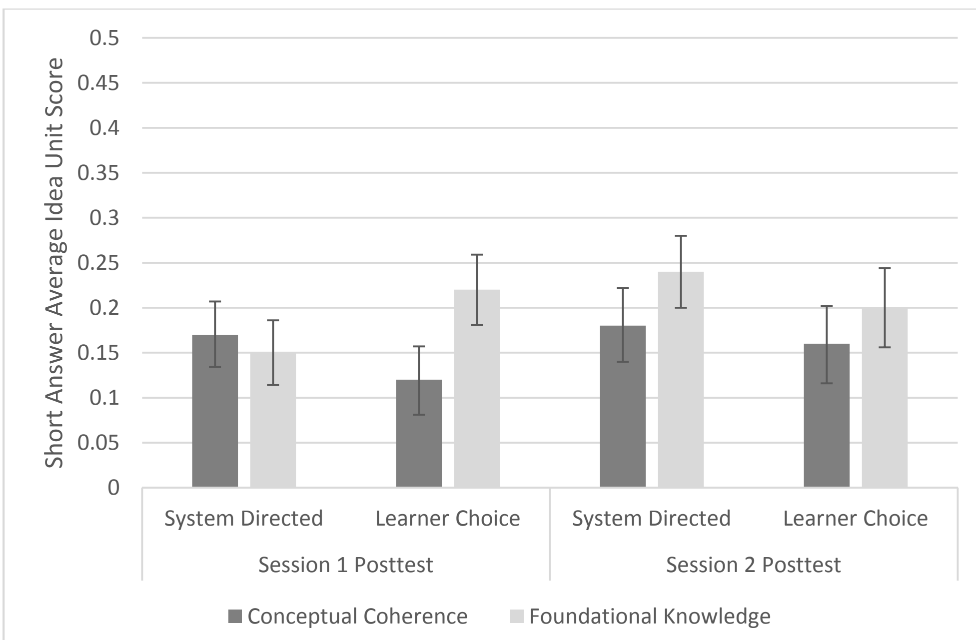

Figure 15. Idea unit scores by learning path and learner control conditions at test times two and three.

Table 9

Description of Experimental Conditions

	Conditions	Learning Path Foundational Knowledge	Conceptual Coherence
Learner Control	System-Directed	Next concept to address is chosen by the system + Concept order based on foundational knowledge (*n* = 17)	Next concept to address is chosen by the system + Concept order based on conceptual coherence (*n* = 16)
	Learner-Choice	Next concept to address is chosen by the learner (within learning path constraints) + Choices available are based on foundational knowledge (*n* = 15)	Next concept to address is chosen by the learner (within learning path constraints) + Choices available are based on conceptual coherence (*n* = 16)

Table 10

Means and (Standard Deviations) of Observed Revisions and SRL Strategies

	Number of revisions	Number of effective strategies	Number of ineffective strategies
Foundational Knowledge + System Directed	16.35 (7.7)	9.06 (7.0)	6.47 (6.9)
Foundational Knowledge + Learner Choice	14.87 (7.6)	6.40 (4.9)	8.27 (6.9)
Conceptual Coherence + System Directed	11.06 (5.1)	4.44 (4.9)	6.56 (5.1)
Conceptual Coherence + Learner Choice	15.81 (6.5)	5.63 (3.6)	9.44 (7.9)

Table 11

Means (and Standard Deviations) for Learning Outcomes

		Foundational Knowledge		Conceptual Coherence	
		System Directed	Self Directed	System Directed	Self Directed
True/False Measure % Correct	Session 1 Pretest	.67 (.08)	.70 (.08)	.70 (.09)	.63 (.13)
	Session 1 Posttest	.76 (.12)	.74 (.10)	.76 (.08)	.72 (.08)
	Session 2 Posttest	.76 (.09)	.75 (.14)	.80 (.07)	.77 (.08)
Inference Measure % Correct	Session 1 Pretest	.16 (.22)	.31 (.29)	.09 (.13)	.20 (.22)
	Session 1 Posttest	.36 (.29)	.29 (.26)	.26 (.24)	.35 (.24)
	Session 2 Posttest	.45 (.25)	.47 (.25)	.38 (.22)	.45 (.23)
Short Answer Application % Correct (Idea Units)	Session 1 Pretest	.09 (.14)	.11 (.15)	.09 (.10)	.08 (.09)
	Session 1 Posttest	.15 (.15)	.22 (.14)	.17 (.13)	.12 (.16)
	Session 2 Posttest	.24 (.21)	.20 (.14)	.18 (.11)	.16 (.17)
Short Answer Application % Correct (Quality)	Session 1 Pretest	.20 (.15)	.27 (.16)	.22 (.09)	.21 (.15)
	Session 1 Posttest	.36 (.15)	.37 (.16)	.32 (.15)	.27 (.16)
	Session 2 Posttest	.42 (.20)	.38 (.16)	.34 (.12)	.35 (.16)
Structural Knowledge % Correct (Lines)	Session 1 Pretest	.43 (.11)	.43 (.10)	.46 (.08)	.47 (.14)
	Session 2 Posttest	.48 (.11)	.45 (.11)	.50 (.09)	.53 (.11)
Structural Knowledge % Correct (Arrows)	Session 1 Posttest	.30 (.15)	.25 (.14)	.18 (.18)	.29 (.16)
	Session 2 Posttest	.37 (.13)	.32 (.18)	.21 (.20)	.26 (.19)

Table 12

Correlations of SRL Behaviors and Session 2 Posttest Learning Outcomes

	True/ False % Correct	Inference % Correct	Short Answer Application (Idea Unit Rubric) % Correct	Short Answer Application (Conceptual Rubric) % Correct	Structural Knowledge (Lines) % Correct	Structural Knowledge (Arrows) % Correct
Number of Effective Strategies Observed	.02	.09	.06	.16	-.04	.06
Number of Ineffective Strategies Observed	.06	-.26*	-.08	-.10	-.09	.08

Table 13

Means and (Standard Deviations) of Perceptions by Condition

	Foundational Knowledge		Conceptual Coherence	
	System Directed	Self Directed	System Directed	Self Directed
Average Rating on Perception of Utility	3.5 (.49)	3.4 (.42)	3.3 (.50)	3.6 (.40)
Average Rating on Perception of Control	3.4 (.52)	4.1 (.71)	3.3 (.52)	3.8 (.68)

Table 14

Correlations of Perceptions and Session 2 Posttest Learning Outcomes

	True/False % Correct	Inference % Correct	Short Answer Application (Idea Unit Rubric) % Correct	Short Answer Application (Conceptual Rubric) % Correct	Structural Knowledge (Lines) % Correct	Structural Knowledge (Arrows) % Correct
Perception of Control	-.06	.04	-.12	-.02	.19	.16
Perception of Utility	.01	-.01	-.04	-.05	.18	.15

CHAPTER 4

GENERAL DISCUSSION

Results from both experiments demonstrated that following a foundational knowledge path when learning with online resources in a complex domain is beneficial to novice learners. In Experiment 1, foundational knowledge cues resulted in strategic learning approaches: participants executed more effective SRL strategies on concepts cued as more central to the domain and skipped revisions on concepts cued as less central to the domain. Although a nonsignificant trend in Experiment 1 suggested that the foundational knowledge scaffold may have negatively impacted both factual knowledge and conceptual understanding outcomes, this result could be due to the low usage of the foundational knowledge cues during the learning task or to the fact that participants explored only problematic foundational concepts (rather than all important domain concepts). In Experiment 2, conditions that followed a foundational knowledge learning path demonstrated positive deep learning outcomes and those participants correctly indicated causal relationships more frequently than the conceptual coherence participants. Thus, participants in the foundational knowledge conditions developed a deeper understanding of how concepts were related within the domain. Participants in the foundational knowledge conditions also executed more effective SRL strategies in

Experiment 2 than those in the conceptual coherence conditions. Overall, this research demonstrates that learners studying along a foundational knowledge path develop better conceptual understanding of the domain material and more successfully execute effective SRL behaviors, such as synthesizing information from multiple online resources into a written deliverable.

The impact of learning along a foundational knowledge path is somewhat surprising given findings from prior research that have shown the effectiveness of conceptual coherence paths in learning from hypertexts (Salmerón et al., 2006, 2010). Despite results showing that coherent learning paths can improve knowledge outcomes, research also has found that low-knowledge learners do not spontaneously choose coherence-based baths. Indeed, some research has shown that low-knowledge learners may choose paths that serve foundational learning goals. Salmerón et al. (2010) studied how SRL strategies affect learning path selection through hypertext resources by providing participants with two navigation choices after reading a portion of hypertext: one option was strongly semantically related to the hypertext the participant just read and the other was weakly related (based on the cosines of a latent semantic analysis). The concepts presented were condensed into hypertext titles, for example, “The 3 Forms of the Black Death” with the subsequent choices for learners to navigate to “The Septicemic Type of The Epidemic” or “Interruption of Philosophical & Scientific Development” (Salmerón et al., 2010). In the example quoted, the conceptually coherent choice would be “The Septicemic Type of The Epidemic,” which presumably discusses a particular form of the Black Plague virus. However, the other option, “Interruption of …,” is actually another key idea to understanding the history of the Black Plague. Salmerón et al. (2010) found that low prior knowledge learners more often chose a learning path that led to the weakly related option than to the option deemed as more conceptually coherent. Learners may have been navigating to the less coherent option more frequently in an effort to gain a broader, and more foundational, understanding of the domain rather than dive deeper into the current subtopic as intended by the path of coherence in the study.

In fact, more recent research into supporting hypertext comprehension with graphical organizers demonstrates the positive impact of a foundational knowledge learning path that spans the breadth of a domain while learning from digital resources. Amadieu and Salmeron (2015) investigated prior knowledge activation effects on hypertext comprehension by comparing reading a sample of domain content prior to constructing concept maps from given domain ideas (from which hypertexts were accessed via the concepts for a learning task) compared to forgoing the prereading and creating the concept map first. Eye tracking data revealed that participants who read a series of hypertexts and then completed the concept mapping task focused on the domain core concepts but not the core concept *relationships* when completing the learning task (Amadieu et al., 2015). One could argue that the learners were trying to construct a foundational knowledge framework of the domain in preparation for the next part of the learning task that would require integration of additional domain concepts and details, choosing not to focus on the conceptual relationship details until a baseline understanding had been attained. Moreover, low prior knowledge participants who completed the concept mapping exercise first demonstrated low “navigational coherence” (Amadieu et al., 2015), meaning that they were less likely to select a conceptually coherent concept to study next. Thus, as new tools are developed to assist learners in comprehension of complex, digital resource collections, they should take into consideration ways to expose or make explicit foundational knowledge frameworks of the domain being studied, especially for novice learners.

Further interpreting the results from a cognitive perspective, the foundational knowledge path may have been effective for promoting deeper learning in this study by creating a level of desirable difficulty (Bjork, 1994) and inducing a state of productive confusion for the learners (B. Lehman, D'Mello, & Graesser, 2012). Because participants navigated ideas in a perceptually disconnected manner (i.e., they did not move along the conceptual relationships made explicit in the graphic organizer), extra effort on the participants' part was required to synthesize and infer relationships between concepts across various locations in the organizer. This design could have prompted a state of productive confusion for the learners because there was no explicit scaffold to suggest a reason for why the next concept was selected. Prior research in digital resource-based learning environments has found that a state of confusion can promote deeper learning of conceptually difficult material (D'Mello, Lehman, Pekrun, & Graesser, 2014; B. Lehman et al., 2012). Lehman, D'Mello, and Graesser (2012) studied four digital environments and found that when feedback, learning scaffolds, or challenging instructional material caused a state of confusion for learners, they performed better on measures of conceptual understanding. Lehman, D'Mello, and Graesser (2012) argue that when learners are aware of their confusion and they attempt to resolve it they are exerting more cognitive effort to make sense of and integrate the disparate pieces of information. Thus, in this study, when participants were forced to learn concepts that were further away from one another, as dictated by the system-directed, foundational knowledge condition, it resulted in a more difficult challenge of integrating those ideas with one another and into the general domain knowledge the participants were developing. When participants were given the goal to understand the domain and the task to write a coherent essay, it may have motivated them to try to connect important but not obviously related domain ideas promoting useful cognitive effort.

Regarding observed SRL behaviors in this study, participants on average executed effective SRL strategies approximately 50% of the time and ineffective strategies the other 50% of time in Experiment 2. Prior research indicates that learners struggle to spontaneously engage in any effective processing and to deploy SRL strategies unprompted when learning from a resource-based online environment (Azevedo, Cromley, & Seibert, 2004; Goldman et al., 2012; Thompson, 2013; Winne & Perry, 2000). Thus, an important question is whether or not 50% execution of effective SRL strategies can be counted as successful. Comparing to prior research is difficult because execution of SRL strategies is quantified in different ways; for example, most of the research from Azevedo and colleagues (Azevedo et al., 2007; Azevedo & Cromley, 2004; Azevedo, Cromley, et al., 2004; Azevedo & Witherspoon, 2009) report proportion of learners using processes (captured via verbal protocols) and strategies, not percentages of strategies executed per learner. Thus, comparing whether or not automatic scaffolding in this study is more or less effective than providing an adaptive, human tutor to assist in external regulation is not possible using the existing literature. However, current data warrants some comparison to Goldman et al. (2012). Goldman et al. (2012) reported the mean proportion of effective SRL strategies for better versus poorer learners, specifically that better learners make goal-oriented navigation decisions approximately 15% of the time while poorer learners only execute that effective strategy 10% of the time. Better learners also monitored their emerging understanding and evaluated resources more often (13% and 10%, respectively) than poorer learners (7% and 8%; Goldman et al., 2012). In the current study, learners across almost all conditions were executing roughly the same proportion of effective and ineffective strategies. Although this study did not find 100% adherence to effective SRL strategy usage, the fact that effective strategy usage was almost as frequent as ineffective strategy usage could be seen as a successful outcome and bodes well for future design efforts that include more automatic scaffolds to support effective SRL during online learning.

Additionally, the nature of the learning task could also have had an influence on the learning outcome results and observed SRL behaviors. Prior research has shown that learners who frequently utilize digital resources for information tend to rely on those digital resources as memory aides, offloading cognitive effort to memorize information for future use and instead returning to the digital resource for that information (Storm, Stone, & Benjamin, 2017). By providing access to many digital resources with new and complex information, participants may have relied on the learning environment to hold some of that information than spend effort integrating that information for long-term retrieval. Moreover, the task of writing to learn may have further affected the results. Researchers who study the psychology of writing have noted the integral connection between a learner's metacognition and the act of writing, such that the external representation of knowledge (i.e., the written product) is the product of one's metacomprehension that undergoes revisions as it is generated into the external representation through a series of self-regulated processes and behaviors (Bereiter &

Scardamalia, 1987; Hacker, Keener, & Kircher, 2009; Hayes, 1996). Several models of writing psychology propose that learners establish subgoals in order to accomplish the writing task, which involves executing SRL processes such as planning, metacognitive monitoring, and reflection (Bereiter & Scardamalia, 1987; Hacker et al., 2009; Hayes, 1996). As previously noted in this manuscript, SRL processes can lead to and inform SRL behaviors (Zimmerman, 2002). Thus, the nature of the writing task in this experiment may have, by itself, promoted SRL behaviors. While the presence of feedback and scaffolds, particularly in Session 2 of the experiments, can assist learners in helping to direct their own goal setting (Flower, Hayes, Carey, Schriver, & Stratman, 1986; Franzke & Streeter, 2006), the presence of scaffolds in the learning environment may not have been strong enough cues or supports to encourage more SRL behaviors than triggered by the writing task itself. Indeed, research on scaffolded writing environments has found that learners make stronger comprehension gains when they have guided practice and content-specific feedback over multiple iterations of a writing cycle (Franzke, Kintsch, Johnson, & Dooley, 2005; Franzke & Streeter, 2006; Wade-Stein & Kintsch, 2004).

4.1 Potential Limitations

Potential limitations of this research include sample size and amount of exposure to the learning materials. Although enough participants were included in both studies to find small effect sizes, the question of which learning path is most effective for learners should be further investigated with a larger sample before any strong conclusions can be drawn. Additionally, future iterations of this research should consider increasing the amount of time that learners spend with the informational resources in the SRL environment. Participants in this research were exposed to the learning path and resources for only 30 minutes during Experiment 1 and for a total of 1 hour during Experiment 2. Although prior research indicates that learners who turn to online materials for SRL often conduct quick information searches (Thompson, 2013), we would expect that the longer a learner can spend in the educational materials processing both the information presented and the learning path cues would positively impact learning outcomes. One hour to learn a complex domain and decipher the visual cues of a graphical organizer may not be a substantial learning opportunity for true novices.

4.2 Future Directions

Future directions warranted by the current research include further investigating findings of an interaction between learning path and learner control factors as well the unexpected result in foundational knowledge conditions developing a deeper understanding of conceptual relationships than the conceptual coherence conditions. Both topics are discussed further.

In Experiment 2, a three-way interaction between time, learning path, and learner control was discovered, which further analysis revealed that earlier in the learning task, self-directed foundational knowledge condition performed best on a deep knowledge assessment. Both system-directed conditions performed decently, and self-directed conceptual coherence condition had the lowest scores. However, in the subsequent test time, system-directed foundational knowledge participants demonstrate the highest performance, with self-directed foundational knowledge and the system-directed conceptual coherence conditions performing on par with one another. The interaction of time and control could be further explored as a potential system design that adds in system direction over the course of a learning task. In prior research on cognitive load, researchers found that only necessary information for being able to complete the immediate task should be used in instruction so as not to overwhelm novice learners with too many (potentially irrelevant) details, allowing a schema to be built for which further information could be integrated over time (Harp & Mayer, 1998; Kalyuga, Ayres, Chandler, & Sweller, 2003; Kalyuga, Chandler, & Sweller, 2000; Mayer, 2005). Managing a balance of scaffolds throughout the learning experience could be applied to introducing more system restriction to navigate a domain macrostructure as a learner develops a foundational understanding of the domain. It may be possible that learners need more system direction and support after they have developed a basic schema to which additional domain details can be integrated, at which point, a system-directed navigation may assist in directing their processing attention to the next most appropriate concept.

A surprising finding in the current research was that the foundational knowledge participants were better able to glean details about the causal relationships between concepts compared to learners who navigated concepts along a conceptual coherence path. This result could suggest that when learners are navigating along a conceptually coherent path, especially one that provides the conceptual domain relationships via direct links, they may not feel the need to reflect on the relationships and infer why or why not two concepts are connected. Because the connection is supplied for them, this aspect of the visual representation could potentially serve as a crutch to learners following a conceptual coherence path. However, foundational knowledge learners may have to put forth the cognitive effort to understand the conceptual relationships in the broader domain because they are moving around to more distant regions to focus on the central ideas first. Drawing again upon the intelligent tutoring literature, the assistance dilemma (Koedinger & Aleven, 2007) could be an explanation to the previously described result. When learners are provided with too much scaffolding, they may not need to exert cognitive processing to interpret the connections because it alleviates the opportunity for metacognitive monitoring to occur, specifically opportunities for confusion or the identification in missing knowledge to explain how two concepts are related.

APPENDIX A

TRUE/FALSE ASSESSMENT

Table A1

True/False Questions and Answers

The rising and sinking of air cannot cause air currents to form. Air currents form only because of the rotation of the earth.	F
In the Northern Hemisphere, winds blowing from north to south are deflected, or curved, toward the west due to unequal heating of land and water surfaces.	F
Wind results when air moves from a place of lower pressure to one that has higher pressure.	F
Deep ocean circulation is controlled by density differences due to changes in temperature and salinity.	T
Wind exerts a frictional force on the surface of the ocean, causing water at the surface to move relative to the underlying water.	T
Convection currents can transfer thermal energy in liquids and gases but not in solids.	T
When ocean water moves to a place where the air above it is colder than the water, the warmer water transfers thermal energy to the air, making the air warmer and the water colder.	T
Thermal energy is transferred around the earth by the movement of air in the atmosphere but not the movement of ocean water.	F
If someone wants to live in a place that is warmer than where that person lives now, s/he needs to consider the distance of the place from the equator and not its height above sea level.	F
The air temperature range is usually smaller the closer a place is to an ocean.	T
Places at the same latitude will have the same high temperatures on a given day even if they are at the same elevation and the same distance from the ocean.	F
When a container of water is warmed over a flame, warmer water at the bottom rises toward the top and the colder water at the top sinks toward the bottom	T
The temperature of land cannot affect the temperature of air as the air moves over the land.	F
The amount of water vapor in air is affected by the oceans, rivers, and lakes beneath the air, but the temperature of the air is not.	F

Energy from the sun increases the temperature of the land, but it does not increase the temperature of the water.	F
Typical ocean surface currents are usually much slower moving than deep ocean currents.	F
Upwelling is the upward movement of ocean water from the deep ocean to the surface.	T
Ocean currents regulate the Earth's temperature by removing heat from the equator and carrying it towards the poles	T
The pattern of ocean circulation remains constant throughout the year.	F
The northeastward flow of the Gulf Stream ocean current is caused primarily by atmospheric winds	T
The jet stream is the name for a fast moving stream of air in the upper atmosphere.	T
Jet stream winds are faster in winter than in summer due to a greater north-south temperature gradient in winter.	T
Trade winds are bands of wind near the equator that move west to east.	F
Wind direction is indicated by the compass direction the wind is blowing toward.	F
As air moves from one place to another, its thermal energy moves with it.	T

APPENDIX B

SHORT ANSWER APPLICATION ASSESSMENT

B.1 Wind and Ocean Currents Question

B.1.1 Prompt

The map below shows the pattern of surface ocean currents across the globe. Knowing that the wind influences surface ocean currents, would a map of wind currents across the globe look the same as the map below? Why or why not? Please explain the reasons for your answer and discuss at least one specific example from the map below.

B.1.2 Idea Unit Rubric

Each idea unit was awarded points; points are indicated in brackets. A maximum of four points was awarded on this idea unit rubric:

- [1 point] Global winds form three separate bands in each of the northern and southern hemispheres.
- [1 point] The trade winds, near the equator blow east to west much like the equatorial currents. In the mid latitudes, the prevailing wind is from the west, and in the poles the prevailing wind is from the east.
    - Alternatively, they can describe this via the Coriolis Effect: The Coriolis effect deflects the prevailing winds clockwise in Northern Hemisphere and counterclockwise in the Southern Hemisphere which in turn deflects the ocean surface currents.
- [1 point] So the general pattern is similar to the ocean currents,
- [2 points] However in the ocean, the currents are impeded by the continents
- [1 point] which creates cyclical patterns called gyres.
- [1 point] example of a continent impeding the movement of currents in the map

- [1 point] Gyres in the northern hemisphere move in a clockwise direction and those in the southern hemisphere move in a counterclockwise direction

B.1.3 Conceptual Explanation Rubric

The conceptual explanation rubric for this question is outlined in Table B1 below.

Table B1
Description of Conceptual Explanation Rubric

Score	Category	Examples
0	Answer contains no domain-specific content.	"Yes and no." "The wind influences the ocean direction." (*RESTATES PART OF THE QUESTION)*
1	Irrelevant or Wrong Concepts	"Depending if its hurricane or tornado season." (*EXTREME WEATHER is not a causal explanation for wind patterns)*
2	Vague, incomplete, or incorrect application	"No I don't think so, because wind influences surface ocean currents. Not necessarily effecting the deeper parts of the ocean." (*Incorrect application of deep ocean currents but it is still relevant to the domain)*
3	Principle or process naming	"Yes. Surface ocean currents flow in the direction of the prevailing winds"
4	Knowledge revision or addition	"One example, is the winds which go from the western coast of South America, directly west towards the eastern coasts of Australia and Asia. These are caused by a jet stream which flows in this same slightly north, western direction. It is the same with the winds that go along the southern part of the map in an eastward direction, they are also caused by wind movements which flow in the same direction."
5	Principle-based explanation	"No, a map of global wind currents would look somewhat similar but not identical to the map of ocean currents above. Wind currents are not affected by the placement of continents in the same manner as ocean currents are. Therefore a map of wind currents would indicate a much more organized pattern, as well as less cyclical movements as are depicted above. A specific example of this is the area of western North America where there is a cyclical ocean current pattern - a wind current in this area would remain on a straight path as it is not affected by the continent."

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